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The Effect of Fluid Periodization on Athletic Performance Outcomes in American Football Players

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THE EFFECT OF FLUID PERIODIZATION ON ATHLETIC PERFORMANCE OUTCOMES IN AMERICAN FOOTBALL PLAYERS

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Education
at the University of Kentucky

By

Christopher Whaley Morris

Lexington, KY

Director: Dr. Mark Abel, Associate Professor of Exercise Physiology

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2015

ABSTRACT OF DISSERTATION

THE EFFECT OF FLUID PERIODIZATION ON ATHLETIC PERFORMANCE OUTCOMES IN AMERICAN FOOTBALL PLAYERS

For decades strength and conditioning professionals have been seeking optimal training volumes and intensities to yield maximum performance outcomes without the onset of injury. Unfortunately, current studies apply experimental training techniques without considering the individuals' response to the imposed training load. Due to the vast genetic variability and extraneous environmental factors that affect one's ability to recover, results from such studies are controversial and inconclusive. Athlete monitoring systems offer an objective assessment that is purported to evaluate an individual's physiological readiness to adapt to an overload stimulus and thus allow for daily manipulations in training loads (i.e., fluid periodization). However, little is known about the efficacy of this technology to enhance training outcomes. Therefore, the purpose of this study was to examine the effect of fluid periodization on performance outcomes in American football players. Sixty-one Division 1 collegiate American football players (Age: 19.7 ± 0.9 yr; Height: 1.88 ± 0.3 m; Mass: 107.3 ± 11.1 kg) participated in this study and were stratified into experimental (n=33) and control (n=28) groups. Performance outcomes were measured prior to and following the summer training program. Physiological readiness parameters (heart rate variability and direct current brain wave potential outcomes) were measured daily in the experimental group only with Omegawave technology prior to training sessions and adjustments in training volumes or intensity were made based upon physiological readiness outcomes. The control group trained according to the daily prescribed workout. The findings from this study indicate that the experimental group significantly improved in vertical jump, vertical power, aerobic efficiency and broad jump ($P < 0.01$) compared to the control group. Additionally, significant improvements and effect sizes between groups were noted for fat-free mass (relative improvement: 54%, effect size: 0.30), vertical jump (relative improvement: 157%, effect size: 1.02), vertical power (relative improvement: 94%, effect size: 0.86), broad jump (relative improvement: effect size: 592%, 0.81), triple broad jump (relative improvement: 338%, effect size: 0.63), aerobic efficiency (relative improvement: 154%, effect size: 1.02), and medicine ball overhead throw (relative improvement: 50%, effect size: 0.26). In addition, the experimental group achieved these improvements with less core (-9.5%) and accessory (-13.2%) training volume ($P < 0.01$). In conclusion, fluid periodization produced greater improvements in performance outcomes at a reduced training load compared to a similar unmodified periodization scheme. These findings highlight the importance of modifying training parameters based upon the daily physiological state of the athlete.

KEYWORDS: American football, Fluid Periodization, Collegiate athletes, Training volume, Performance outcomes

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May 7, 2015

(Date)

THE EFFECT OF FLUID PERIODIZATION ON ATHLETIC PERFORMANCE OUTCOMES IN AMERICAN FOOTBALL PLAYERS

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CHAPTER I

INTRODUCTION

For decades, strength and conditioning professionals have sought to identify an optimal training volume that elicits the highest physiological outcomes while reducing the risk of overtraining and injury. To that end, researchers have attempted to objectively define overtraining by identifying micro-level biomarkers that contribute to overtrainning (67) (163). The conclusions of these investigations have produced inconclusive and contradictory results due to variability between studies. Although molecular biology provides valuable information, it fails to properly illustrate the integrative physiology of an organism that is constantly adapting to its environment. Thus, an integrated physiological approach must be taken to examine athletes as a whole, rather than focusing on their individual components.

Regardless of the training stimulus applied to the athlete, it should not be assumed that adaptation occurs at the same rate between individuals. Genetic endowment may be considered the largest determinant of athletic potential (23) and may account for up to half of the variation observed between athletes (136). Beyond genetics, collegiate athletes are subjected to academic loads, technical/tactical loads, psychological loads, and lifestyle loads. Each load represents a different stressor and its magnitude is specific to the individual. These loads must not be thought as single action resulting in an equal or opposite reaction as implied by Newtown's Third Law. The human organism is a dynamic integrative organism, therefore loads should be considered cumulative (i.e., allostatic loads), with each action eliciting an exponential reaction (Chaos Theory).

Given the individual variance between athletes, all loads acting on the athlete must be assessed to properly monitor the body's ability to adapt to functional stress.

Allostatic loads are specific to the individual and can vary at random times due to the constantly changing environment for the athlete. Strength and conditioning professionals can meticulously calculate training loads and present a perfect blend of training modalities to elicit specific physiological adaptations, however, too many environmental factors can disrupt the process of adaptation. Even the genetically gifted athletes may become maladaptive given unhealthy environmental conditions. It is simply impossible to calculate metabolic cost, or allostatic load, resulting from additional external stressors such as academic preparation or relationship disputes. These metabolic costs inherently deprive the athlete of resources that could potentially be used towards the functional adaptation response, specifically the resources needed for protein synthesis for the desired training effect.

To date, many coaches have employed several methods for monitoring the training process. Subjective assessments in various forms provide information to the coach about the athlete's psycho-physiological state including mood, quality and quantity of sleep, soreness, stress levels, etc (64). Although it has been shown to be a reliable method for obtaining information, subjective questionnaires may be influenced by fear of retribution for poor responses. Various researchers have used biological markers such as cortisol, testosterone, and creatine kinase for assessment (69) (56), however these methods are invasive, time consuming, and are not descriptive of the athlete as a whole. Lastly, many coaches will employ a "watch and see method" by observing reactions to training and analyzing performance outcomes. This method presents problems as the observed variables only reflect external outcomes and negates the internal adaptation cost to achieve such outcomes. Although all of these methods are informative and useful, a single scientific method will not provide a comprehensive analysis of the athlete. Accordingly, an integrated model of physiological monitoring should be implemented so that performance may be enhanced and injury risk reduced by applying alterations to training volumes and intensities based on physiological feedback.

To properly guide the training process, a comprehensive examination of the athlete must be utilized. As part of the training process, coaches must be able to identify the athletes “readiness” to train. Readiness may be defined as the current functional state of an individual that determines their ability to achieve their performance potential (47). Additionally, this approach must be non-invasive, non-exhaustive, provide immediate information, and must be performed continuously to control the training process. One method which meets the above criteria is provided by athlete monitoring systems (AMS). Athlete monitoring systems provide an integrated assessment of the athlete’s readiness for training loads. Certain systems provide an assessment of the athlete’s cardiovascular and central nervous system by measuring heart rate variability (HRV) and direct current (DC) potentials of the brain.

Heart rate variability has been introduced to athletic populations over the past 20 years. It’s a simple, quick, and non-invasive measurement of the athlete’s autonomic tone which can indicate the functional state of readiness of an athlete on a given day. For example, an athlete who presents sympathetic dominance of autonomic tone indicates his body is under some sort of allostatic load. Within the body a metabolic need is desired which is represented by the activation of the sympathetic nervous system. Given that

HRV measurements are done in a supine rested state, the ability of the athlete to receive a training load in a sympathetic state is limited. Adding a stress to a stressed system will increase the allostatic cost of maintaining homeostasis and will ultimately lead to extended recovery periods. One can think of HRV outcomes as an indicator of the available resources for adaptation to occur (i.e., fuel tank), whereas the DC potential is an indicator of how powerful the engine (brain) is to regulate the adaptation processes.

The DC potential has been used as an overall indicator of the functional state of the athlete (78). According to Anokhin's Functional Systems Theory, the brain represents the central component of all adaptive qualities of the human organism. The DC potential is thought to represent the overall capacity or functional state of the organism's ability to handle or adapt to allostatic loads. Given that athletes have an estimated millions of functional systems specific to their given sport, a reduced functional state, as indicated by the DC potential, can represent not only a limited ability to perform a skill or task such as sprinting, throwing, or changing direction, but also a limited ability to secure quality adaptions by coordinating the adaption process. Both HRV and the DC potential are vitally important to securing optimal training results and the use of both technologies appear to be essential in an AMS.

With the guidance of AMS, optimal applications of training volumes and intensities can be established. Periodized training attempts to provide a model which applies the appropriate amount of training stimulus while offering times of recovery to allow supercompensation to occur. Although this model and its variants have been shown to be successful, with limited research suggesting one method is superior to the other (61), it fails to account for the many factors contributing to impaired adaptation. It is not the contention of the author to dispute the efficacy of periodized training, however the use of AMS should be used to compliment the training process. The use of AMS makes the training process fluid in the fact that training loads can be altered based upon the objective assessment of the adaptive capabilities of the athlete on a given day. Thus, the utilization of an AMS in combination with periodized training could be thought of as "fluid periodization".

In theory utilizing AMS will broaden the fine line between overload, overreaching, and overtraining the athlete. Without this insight, overreached and overtrained athletes may go undetected leading to mal-adaptation and injury. (29) By controlling the training process through objective integrative physiological measures, athletes will recover sufficiently from training stimuli before applying the next training stimulus, thus increasing performance outcomes. Additionally, the modified training volumes and intensities may increase performance outcomes while decreasing the physiological cost.

Athlete monitoring systems have been validated in athletic populations (17) (128) (114) and data from our lab suggests that AMS's output corresponds to the short term training response and functional states of individual athletes. However, there is limited research evaluating the efficacy of using an AMS to promote longitudinal improvements in performance outcomes by accounting for allostatic loads prior to training. Without objective feedback regarding the functional state of the athlete, training unabated with traditional periodization strategies may lead to states of overtraining. The training process must remain fluid rather than fixed and utilize an AMS to provide objective measures of the physiological state so that strength professionals can alter external loads (resistance training and running loads) to match the adaptive capability of the athlete. Therefore, the purpose of this study was to determine the effect of a fluid periodization model on athletic performance outcomes guided by an AMS's assessment of athletes' functional state. We hypothesized that the fluid periodization model would:

1. significantly improve broad jump, vertical jump, vertical power, triple broad jump, medicine ball overhead throw, and aerobic efficiency in the treatment group compared to the control group.
2. decrease the total volume of work performed by the treatment group compared to the control group.

Assumptions

Assumptions of this study include the following:

1. It was assumed that all athletes adhered to athlete monitoring protocol as instructed prior to the initiation of the study.
2. It was assumed that strength and conditioning personnel adjusted training volumes based upon the physiological assessment of the athlete.
3. It was assumed all training adjustments were recorded accurately by strength and conditioning personnel.

Delimitations

This study was delimited to the following:

1. Male Divison-1 collegiate American football players attending the University of Kentucky between the ages of 18 to 23 years.

2. Male Division-1 collegiate American football players who were cleared for full activity without restriction at the time of the study.

Definitions

Periodization – The systematic planning of athletic or physical training.

Linear Periodization – Physical Training which involves a gradual, progressive mesocycle increases in intensity over time.

Non-Linear Periodization – Physical training which involves large daily fluctuations in the load and volume assignments.

Flexible Non-Linear Periodization – Physical training which adjusts volume and load based on a subjective assessment of wellness from the individual.

Fluid Periodization – Physical training which adjusts volume and intensity based upon the physiological assessment of the individual with objective measures.

General Adaptation Syndrome – a term used to describe the body's reaction to short-term and long-term stress.

Compensation – The stage in which athletes begin to repair and reorganize physiological systems which were displaced due to physical training.

Supercompensation – The effect of physical training in which the body adapts by making various biochemical, structural, and mechanical adjustments that lead to increased performance.

Concurrent Training - Training for multiple bio-motor abilities or qualities within the same training cycle.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The Omegawave technology and its concept of “readiness”, has impacted the understanding of the training response, specifically in regards to research in the area of human adaptation to the application of stress. Several schools of thought formed the basis of the readiness concept including the general adaptation syndrome, the nonspecific adaptation organism response theory (150), Anokhin’s functional systems theory (7), and Ukhtomsky’s theory of the dominant (160). These schools of thought lay the foundation upon which heart rate variability and direct current potential of the brain can be applied to the functional state of the athlete. As such, this literature review will describe these schools of thought, discuss how heart rate variability and direct current potential measurements are grounded in these theories, and interpret how these physiological measurements and theories may be used to guide training practices in elite athletes. Additionally, specific adaptations to strength and power will be discussed.

General Adaptation Syndrome & Nonspecific Adaptation

A variety of terms have been used to describe stress as it manifests itself in a multitude of forms. To understand stress, one must acknowledge the works of French scientist Claude Bernard. Bernard recognized that humans maintained an internal stability or *milieu interieur* and as such can withstand an inconsistent external environment (18). Walter Cannon expanded on Bernard’s idea of internal stability as he described cells responding to perturbing stimuli in a dynamic equilibrium which he termed “homeostasis” (27). Nearly forty years after the discovery of homeostasis, Hans Selye discovered the syndrome produced by diverse nocuous agents (150). He would later go on to call this “the general adaptation syndrome.”

It was observed in 1936 that a typical syndrome appears upon exposure to nonspecific nocuous agents including exposure to cold, surgical injury, production of spinal shock, and more specific to this discussion, excessive muscular exercise (150). Hans Selye coined the term “stress” to describe the effect of the acute non-specific nocuous agents. From these observations Selye defined the GAS as the sum of all non-specific, systematic reactions of the body which ensue upon long continued exposure to stress (151). The syndrome manifests itself in three stages: 1) Alarm Reaction: the reaction when suddenly exposed to a stressor to which it is not adapted. If the imposed stressor does not lead to death, the alarm reaction is followed by adaptation or the stage of resistance. 2) Stage of Resistance: complete adaptation with a disappearance of symptoms. However, continued application of the stressor can lead to depletion of adaptation resources or the state of exhaustion. 3) State of Exhaustion: occurs when adaptation resources are fully depleted (152). Regardless of the stress imposed, these sequence of events occur. As such, the terms non-specific stress and non-specific response were used to describe the general adaptation syndrome.

The specific findings of Selye’s original experiments provide several key observations that formulated the three distinct stages of GAS. His first observation showed that a sub-lethal dose of a noxious agent would elicit the same response regardless of the agent imposed. For instance, within 6 to 48 hours after the initial injury Selye observed a rapid decrease in the size of the thymus, spleen, lymph glands, and liver

(150). Additionally, the activation of the hypothalamic-adrenal axis and the release of epinephrine was observed which was consistent with Walter Cannon's observations of the emergency function of the adrenal medulla in pain and major emotions. This sudden shock to the system and subsequent reaction is termed the general alarm reaction.

Following the general alarm reaction, the organism developed a resistance to the noxious agent. Selye noted manifestations of the resistance stage were much different than those of the alarm stage (152). For example, in the alarm stage the adrenal cortex released its store of epinephrine into the bloodstream to the point of depletion. Conversely, in the resistance stage, the cortex accumulated an abundance of epinephrine. Reductions in body weights were observed in the alarm stage while the restitution of body weight was observed in the resistance stage (152). Even when a continuous application of small doses of the noxious agent, the organisms would continue to build resistance at which point the appearance and function of their organs would return to normal (150). However, long term applications were documented with a loss of resistance and the reappearance of symptoms characteristic of the alarm stage at which point the stage of exhaustion has begun (83).

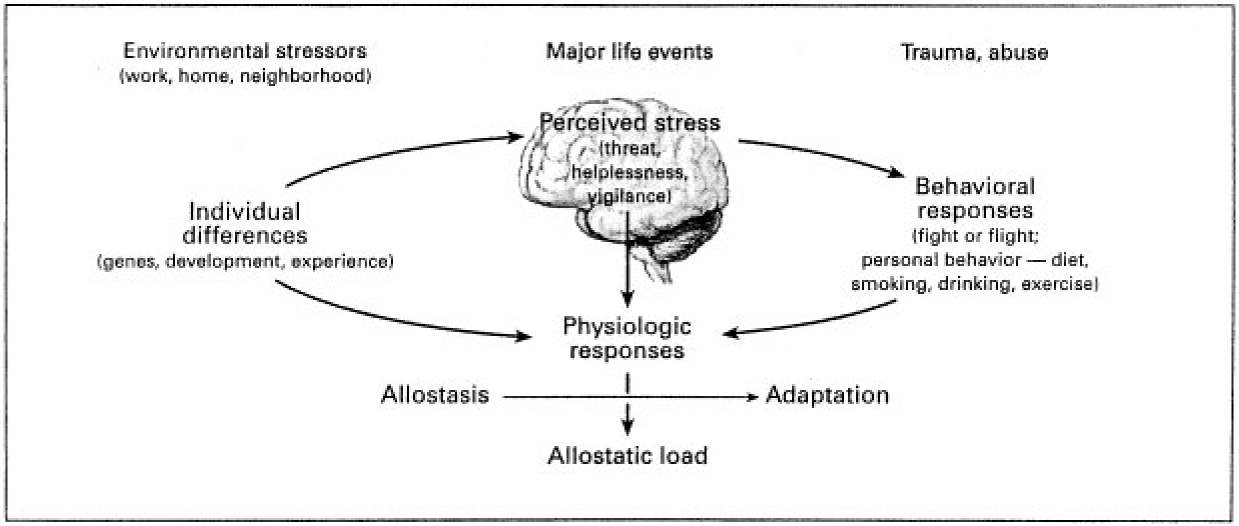
The characteristics of the exhaustion phase could be the most significant relative to training adaptation and to the concept of the athlete readiness. At the time of Selye's first observation, he noted it was difficult to explain the loss of acquired adaptation. He hypothesized that every organism possessed a certain limited amount of adaptation energy and once consumed, the performance of adaptive processes are no longer possible (150). To confirm this hypothesis, Selye introduced two noxious agents of differing natures. During the alarm reaction, the resistance of the organism was increased to both stimuli. However, during the resistance stage, the non-specific resistance of the second noxious agent vanished quickly while the resistance of the initial noxious agent remained elevated. Thus, when an organism’s resistance to a particular stimulus increases, its resistance to some other stimuli of a different nature simultaneously decreases (149). He concluded that adaptation to any stimulus is always obtained at a cost, namely, the cost of adaptation energy (149).

Allostasis and Allostatic Load

Stress is defined by Hans Selye as the common denominator of all adaptive reactions in the body (152), however chronic stress can result in a failed attempt to respond sufficiently to environmental factors. Many have criticized Selye’s work citing several reasons for discrediting his view of stress in relation to normal human activity. Claims against Selye argue that his use of noxious agents are not relative to common stress incurred by the human organism and the controlled environment of animal testing is not extrapolative to human nature (165). However, the masses are still in accord that non-specific stressors elicit a non-specific response relative to the magnitude and intensity of such stressors. Since its inception, the term “stress”, has become an ambiguous term to describe the multitude of challenges the body copes with on a daily basis. This ambiguity has led researchers to develop a more comprehensive view of stress as it relates to adaptation.

The allostasis, allostatic load, and overload concept expands on Seyle's work and offers a more inclusive definition of the stress response and adaptation. Furthermore it highlights the brain's significant role in coordinating the adaptive process through several stress mediators. Allostasis, meaning "maintaining stability through change", was first introduced by Sterling and Eyer to describe the cardiovascular systems response to resting and active states (156). The physiological responses of the autonomic nervous system, hypothalamic-pituitary-adrenal axis, cardiovascular, metabolic, and immune system ensure the protection and adaptation of the organism to perturbations. However, these adaptations occur at a price and the allostatic load represents the cost of the adaptation (118). A schematic of allostasis and allostatic load is represented in Figure. 1.

Figure 1. The stress response and the development of allostatic load



Adapted from McEwen, 1998

McEwen's work is not meant to disregard or disprove Selye's theory of non-specific responses to noxious agents, however it should be viewed as an expansion to the idea that all factors requiring homeostatic re-establishing have a replicable and predictable response in activating the sympathetic nervous system. McEwen simply acknowledges the various factors, specifically mental stress, that have profound impacts on the human organism. Specific to athletes, increased allostatic loads could potentially have significant impacts on short term and long term adaptations.

Alternatively, allostatic load can be viewed as the cost of adaptation. Athletes experience loads of physical stress through training and require ample amounts of rest to compensate or recover from the costs of those loads. Collegiate athletes also endure massive amounts of mental stress through academic loads and tactical preparation such as film study. It has been shown that the body only has limited amounts of adaptation energy, as proposed by Atko Viru, and once those energy reserves are depleted, the stress response or decompensation response (reported by Selye) can occur (166). The foundation of fluid periodization stems from identifying the allostatic load on an individual basis. Since collegiate athletes are exposed to a multitude of environmental stressors such as school, work, relationships, etc., it is important to have objective measures of allostatic load. Attempts have been made to quantify allostatic load by measures of immune function, biochemistry, neural, and neuroendocrine markers in athletes (4) (164) (124). However, evidence to support the use of these measures to identify overreaching/overtraining in athletes has been contradictive and inconclusive (120). Discrepancy in literature can be attributed to several factors, however the most conspicuous factor can be attributed to the law of individual differences (86). External and internal loads must be properly balanced on an individual basis to ensure adaptive reactions occur and the use of AMS may offer objective measures of quantifying internal loads. Through the use of fluid periodization, controllable external loads (frequency, intensity, time, and type of resistance training) can be manipulated to achieve load balance.

Functional Systems Theory and Ukhtomsky's Theory of the Dominant

A French philosopher, Rene Descartes, was the first author to describe the reflex theory of action. He noted that humans and animals are merely machines whose motor behavior is reflexive and independent from the mind (41). This theory remained accepted for nearly 235 years until John Dewey established that the reflex arc was indeed mediated by the "mind." Dewey stated that all neurological reflexes begin with an external or internal source of stimulation, proceed to a central regulating system, and discharge through efferent pathways (43).

Ivan Pavlov began the objective study of higher nervous activity with his theory on conditioned reflexes. Conditioned reflexes satisfied a host of situational experiments, however it did not wholly represent the complexity of which the animal mind works. Specifically, conditioned theory failed to describe goal-directed behavior in which subjects respond to an external stimuli, but overcome obstacles, potentially sacrificing its life, in search of desired environmental clues. He referred to this event as a *goal reflex* (129). However, this term was ambiguous in nature and had limited application. The thought of a systematic organization of higher nervous activity and peripheral physiological functions was beyond the scope of Pavlov's laboratories. However, the development of functional systems theory stemmed from Pavlov's precedential works.

The theory of functional systems was developed by Pyotr Anokhin and would resolve the observations unexplained by Pavlov's experiments. Anokhin's work is not contradictory of Pavlov's theories, yet an extension of the idea that many physiological functions are controlled from higher nervous activities. In addition to Pavlov, Anokhin relied heavily on A.A Ukhtomsky's principle of the dominant, which proposes the internal state (dominant) of the human or animal organism can be a motive force of behavior and determine the subject's active attitude towards external stimuli (160). This principle was established based up the consistently observed fact that "…in normal activity of the central nervous system, its ongoing, varying tasks in a continuously changing environment evoke in it varying 'dominant foci of excitation,' and the foci of excitation, attracting to themselves newly arising waves of excitation and inhibiting other central mechanisms, can substantially alter the operation of the centers" (161). This was a phenomenon that was experienced in Pavlov's experiments yet went unexplained at the time.

Pavlov's experimentation with dogs revealed two important discoveries, one of which was not easily described. Many are familiar with Pavlovian conditioning, or classical conditioning, a type of learning behavior that occurs when a conditioned stimulus is paired with an unconditioned stimulus to elicit an unconditioned response (130). In Pavlov's experiments, it was observed that dogs would begin to salivate (unconditioned response) when presented with meat powder (unconditioned stimulus). He then rang a bell (conditioned stimulus) prior to giving the meat and after several trials of pairing the dogs would begin to salivate upon the ringing of the bell regardless if the meat powder was provided. He referred to this observation as a conditioned response and would later refer to it as a conditioned reflex.

The other unexplained phenomenon was observed when the feeding conditioning was only successful in hungry dogs. Pavlov repeated the experiment as before, giving a conditioned stimulus (bell ring), only this time the dogs had been fed prior to initiation of the experiment. Pavlov did not observe the same conditioned reflex as reflected in the previous trial where dogs were hungry. The dominant need in a satiated dog was no longer food and despite the conditioned stimulus, the conditioned feeding reflex did not appear. Pavlov was unable to grasp this phenomenon as it violated his theory of conditioned reflexes. He attempted to describe an integrated physiological system by breaking it down into simple biological constructs. Anokhin proposed the functional system theory as an alternative to the concept of reflexes. He described the functional system as “a complex of neural elements and corresponding executive organs that are coupled in performing defined and specific functions of an organism….various anatomical systems may participate and cooperate in a functional system on the basis of their synchronous activation during performance of diverse functions of an organism” (6).

Anokhin describes two types of functional systems; systems that maintain the parameters of the internal milieu, and one that dictates behavior in regards to the interaction with the external environment. For example, the human organism requires a strict control of blood glucose (internal milieu) and requires the human to interact with the environment to secure nutrients through dietary intake to maintain optimal blood glucose parameters. Once blood sugar begins to deviate outside its normal parameters, functional systems that maintain the internal milieu initiate a cascade of signals, specifically the release of hormone ghrelin into the blood stream initiating uncomfortable contractions of the stomach. The human organism recognizes these contractions as hunger pains and often will seek nutrients to subside the hunger. Functional systems responsible for the maintenance of the internal milieu via metabolic regulation are determined genetically while others formulate as a current behavioral need arises (6). Together these systems work to govern the activity of the entire organism. As such, Anokhin suggested that functional systems are units of the body's integrative activity (8).

Anohkin proposed that functional systems are more than reflexive responses generated from a stimulus, yet represent the adaptive result of such actions. From this conclusion, the functional system was defined as "dynamic, self-regulating organizations whose activity is directed at securing adaptive results, which are useful for the organism" (7). Adaptive results are the primary factor for each level functional systems including metabolic results, homeostatic results, behavioral results, results of animal zoo social activity, and results from human social activity.

Metabolic results are the products produced to maintain optimal vital functions of tissues and organs at the molecular level. In situations where metabolic results inhibit normal body functions, a need to eliminate metabolic results is essential. Depending on the dominant need at the time, metabolic products will serve to inhibit or accelerate metabolic reactions, each providing advantageous results. For example, a desired adaptation in American football is the ability to repeat highly explosive movements in a relatively short period of time. Through the training process, mitochondrial biogenesis occurs to enhance energy production at the muscular tissue level (106). This adaptation allows the organism to become more efficient at achieving the desired task without depleting its available resources.

Homeostatic results govern the parameters that maintain the dynamic internal milieu. Specifically the dynamic balance of blood and other bodily fluid composition. Rigid constraints of blood nutrients, gases, osmotic pressure, and pH are parameters in which rapid regulatory results are provided, whereas plastic parameters such as blood pressure, temperature, and hormones are typically slower regulatory results. The collaboration of both fast and slow regulatory adaptations ensure normal tissue metabolism. In sport, homeostatic adaptation allows the athlete to respond to extreme conditions quickly and efficiently to achieve optimal performance. It is well-understood the many adaptations that occur when beginning an aerobic conditioning program (116). An untrained athlete will experience hypoxic conditions eliciting high levels of carbon dioxide and lactic acid within skeletal muscle. However, through repeated stimuli ventilation rate increases, respiratory muscles become stronger, the number of capillaries and alveoli increases, stroke volume increases, and oxygen uptake at the muscle level increases. These are a few of many adaptations that occur to allow the athlete to become more efficient at the homeostatic level.

Behavioral results occur when specific biological needs such feeding, hydration, or sexual needs arise from the accumulation of metabolic products in the internal milieu. Many of these needs require the organism to interact with the environment. The acquisition of food, water, and sexual partners meet the internal needs of the body and are achieved by the external results of the behavioral, functional systems. The hypothalamus within the brain serves to initiate the stimulus for such interactions between the internal milieu and the organism's response and interaction with the external environment. For example, an athlete who incurs significant water loss through perspiration in hot conditions will experience a drop in blood volume. Special sensors in the hypothalamus are sensitive to such changes and will provoke sensations of thirst. If fluids are abundant and available, the athlete will seek water to subside these sensations. Thus, an inner need was satisfied through interactions with the environment.

Results of animal zoo social activity are observed when animals in communities set aside individual needs for the benefit of the community. As humans, we may display zoo social activity in relation to one's family and significant other or as a teammate in a sports setting. Often time human behavior benefits others at its own expense in the interest of community survival. This type of behavior will alter the organism's own biological needs. This is the first level where motivation can override the basic needs of the body and is highly prevalent in the sports setting. An athlete may become fatigued, thirsty, and mentally exhausted, however when a victory is eminent, and the team is dependent on the optimal performance of all individuals, thirst will subside, energy will be found, and mental acuity will be obtained. The dominant need at the time was survival of the community at which a particular need was sacrificed.

Results of human social activity are adaptive results exclusive to humans. Results are a representation of accomplishments in everyday activities such as learning, work, recreation, etc. The organism is in constant interaction with the results so that improvements can be made on them. These results allow humans to develop skills that will enhance their intellectual ability with regards to their particular needs. For example, the best baseball players in terms of batting percentage have developed highly specialized functional systems for receiving environmental cues to predict or determine where the potential flight path of a pitch may land. A 100 mph fast ball leaves the pitchers hand and travels to home plate in 400ms. For most humans it takes 200ms to receive a visual stimulus, process it to the primary visual cortex, and initiate muscular contractions to react to the visual object. The 200ms is a latent reaction time among humans and has limited ability to speed up through training. Essentially baseball athletes must begin to initiate their swing shortly after the ball leaves the pitchers hand. The ability to pick up on environmental clues such as hand position on the ball, a pitchers windup, or release will increase the likelihood of making contact with the ball. After repeated exposure and successful attempts, a functional system is created to secure an adaptive result that was useful or beneficial for the baseball athlete. This concept is universal among various sports. A defensive end learns to read the body language of an offensive lineman to predict lane movement, or a soccer player who learns to spin the ball to achieve a specific flight path on set plays. Athletes require highly specific needs dictated by the parameters of their sport. As an athlete progresses through their career from adolescence towards mastery, they enhance their functional systems specific to the desired task. The youngest baseball player learns to hit off a stationary tee at which point a functional system is developed. As the conditions change from slow to fast, the athlete develops new functional systems to achieve the same desired task in making contact with the ball.

The biological needs of an organism are vast and dynamically changing as it progresses through life. A lot of functional systems are developed to produce useful adaptive results in the wake of such needs. Some functional systems define the parameters of the internal milieu while others maintain the organism’s interaction with the environment. The cooperation of the two satisfy metabolic, homeostatic, and behavioral needs of the body so that optimal adaptive results are possible.

Functional systems develop as the current needs of the organism arise. The dominant principle forces the organism to perform a self-organizing role in which needs are attended to in order of which that presents the most dominant threat to homeostasis. Disturbances of parameters of the internal milieu required for healthy metabolism govern the internal biological or metabolic need of the organism. In a system where multiple homeostatic parameters are disturbed, the one requiring the largest metabolic need becomes the dominant. Once satisfied, functional systems self-organize to attend to the next dominant need and so on. Functional systems selectively interact with various systems, organs, and tissues to achieve adaptive results useful for the organism. This regulatory relationship signifies the concept of functional systems as it brings together a dynamic organization of integral systems and functions to secure adaptive constancy.

PHYSIOLOGICAL MONITORING OF THE FUNCTIONAL STATE

The adaptive ability of the body is quite impressive when considering all the potential adaptive responses from environmental stressors. From Selye's model of GAS and non-specific adaptation to non-specific stress to the specific adaption from imposed training loads, the body has been proven to be extremely resilient. According to Selye, an organism has limited amounts of adaptation reserves to non-specific stress. Beyond physical stress of training, athletes endure social stress, academic stress, relationship stress, etc. Monitoring the functional state of the organism gives insight on the current state of stress on the system. This section outlines two mechanisms in which functional states are monitored, direct current potentials of the brain and heart rate variability.

Direct Current Potential of the Brain

Currently, the use of the direct current (DC) potential is widely used in a variety of disciplines around the world (71) (75). It has been studied extensively in Russian laboratories for over 70 years and has been proven to be useful in evaluating the functional state of the adaptive processes in healthy and unhealthy persons, however, research regarding its use in athletic populations is scarce. This section will provide the historical use of the DC potential and the application in athletics as it relates to the adaptive processes and functional status of the athlete.

The human brain is a complex and dynamic organ that drives all functional abilities of the animal organism. Often times it is referred to as the integrative center, an organ that receives sensory input and delivers an output to achieve the desired response. Within the brain lie several centers responsible for functions such as cognitive thought, memory, emotion, motor output, sensory output, and homeostatic control among other things. Constant communication among the brain centers allows for the dynamic interaction between the organism and environment, one that is constantly adapting to meet the required demands.

Communication occurs from neuron to neuron through a series of chemical and ion shifts exciting the electrical membrane potentials of the various neuralgia. Many researchers have studied and measured the electrical activity of the brain through the use of an electroencephalogram (EEG). Credit is given to German physiologist and psychiatrist Hans Berger for recording the first human EEG is 1924 and is renowned for the creation of the first apparatus to record human electrical activity (54). The EEG reflects the electrical activity of the summation of millions of neurons as an action potential of a single neuron would be too difficult to detect. Researchers have distinguished frequency bands that are spatially distributed each with exclusive characteristic. The following table represents EEG frequency ranges and their corresponding location and physiological significance.

Table 1. EEG frequency ranges, corresponding locations, and physiological significance.

Band	Frequency (Hz)	Physiological Significance
Omega	0-0.5	Functional State (78)
Delta	0.5-4	Slow-Wave Sleep (113)
Theta	4-7	Idle State, Repressive Thought processes (87)
Mu	8-12	Motor Neurons (50)
Alpha	8-15	Relaxed & Reflective State (14)
Beta	16-31	Active Thought, Alert or Anxious (104)
Gamma	>32	Memory, Sensory Activation (84)

Each of the frequency bands presented in the table represent a multitude of neurons interacting throughout the cerebrum. The Omega potential holds significant relevance to this discussion as it manifests itself in controlling an organism’s functional state and its adaptive capacities. Thus, the remainder of this review will focus on the Omega potential and its contribution towards adaptation.

Currently, the Omega potential is commonly used among physiologist, medical professionals, and athletic organizations. A variety of terms has been used to describe the Omega potential such as the direct current potential, superslow electrical activity, a quasi-steady difference in potentials, and ultraslow biological potential oscillations. Regardless of the term, researchers generally agree the Omega potential defined as brain bio-potentials occurring within a frequency range of 0-0.5 Hz. The direct current (DC) potential is viewed as the most common and accepted term among Western authors. As such, to avoid confusion, the DC potential will be used throughout the remainder of this review.

The first recording of the DC potential in humans was attempted in 1939 by Davis et al. as he recorded brain potentials in response to auditory stimuli while sleeping (39). The collective group of researchers referred to this phenomenon as the slow component of the "K-complex," yet failed to determine the origin of the DC potential. However, many agreed the brain potentials represented a "quasi-steady change" in the DC and were thought to project from the neural process related to perception. (91)

Many authors and theories have contributed to the application of DC potential in human physiology since it was first observed in the 1930's. Harold Burr, Professor of Anatomy at Yale University School of Medicine, was among the first to establish the concept of a "self-organizing organism" (24). He characterized all life forms to possess a "bio-magnetic" field that exhibited electromagnetic properties that upheld the self-organizing system which regulated all living tissues. This system would be referred to as the “electrodynamic theory of life” which stemmed from research designed to answer the following fundamental questions (24):

1. *Do living organisms possess steady state, or direct current, potential differences?*
2. *Can these potential differences be measured in a way as to be free from the usual ambiguities of electrical measurement?, (i.e., can the determination of potential differences be made independently of resistance changes and current flow?)*
3. *Do these potential differences reflect an unorganized chaos or are they related in such a way as to produce definable electrodynamic fields?*
4. *If such fields are present, are they merely by-products of the living process or are they determinants of the pattern of organization?*

In a matter of time, Burr successfully recorded DC potentials and observed that physical illness would manifest after a measurable change in the organism’s electric field (25). This set up the work of many others to follow, who built upon Burr’s observations and refined the self-organizing system.

Since these precedential studies, neurophysiologists conducted many instrumental studies in animals by recording DC potentials after exposure to a multitude of environmental factors (72). Based upon these studies, scientists mutually agreed that DC potentials represent the slow regulatory system of the brain. According to Ilykuhina, the slow regulatory system of the brain only responds to environmental factors which are exceptionally strong or frequent (72). In contrast, the fast regulatory system of the brain, as measured by an EEG, correspond to stimuli that are weaker or irregular.

Vladimir Rusinov was another influential scientist who exemplified Ukhtomsky's dominant concept in objective measurements of brain potentials in rabbits. Although limited literature translated to English is available, collected works of Ukhtomsky indicated Rusinov was able to demonstrate that the brain will organize itself on dominant foci, and these dominant foci will govern the CNS as it is useful for the organism (160). The works of Rusinov and Burr support the theory that a higher central nervous activity is self-organizing in a manner that tends to the dominant foci that are useful for an organism at any given time.

Up until this point recordings of DC potentials were generated through in-dwelling electrodes placed within the deep structures of the brain. It wasn't until the works of Nataliya Bechtereva and Aleksandrovna Aladzhalova discovered DC potential measurements through EEG that prompted the use of the vertex/thenar method we use today. The observed responses of DC potential in humans and their interaction to various stimuli and environments led them to regard the DC potential as an integrated indicator of the functional state of the human (15). Upon exposure to stimuli of varying degree and magnitude, the DC potential response hypothetically represents the functional state and stress resistance of the body. As such, qualities such as adaptation ability and reserves of the main regulatory systems may be realized (72). The term functional state, in this context, is agreed upon by many authors as "*...such relationships between the components of systems of any degree of complexity and extent of dynamic interaction between these systems and the environment, that are organized in a certain way and are relatively stable at a given time interval" (71).*

As students of Bechtereva's laboratory, Sychev and Ilyukhina are credited for establishing the vertex-thenar method of recording DC potentials (71) (78). This process was highly correlated to the measurements of functional states from in-dwelling electrodes yet provided a non-invasive method for quick diagnosis, one that would become highly applicable in athletic populations. The authors termed the slow waves derived from the vertex-thenar method as "omega potentials" and would go on to call this method of measurement the omegametry method (77). According to Ilykuhina, omega potentials were comparable to (74) *"…the amplitude and time characteristics as integrated parameters of the activation level of (a) the individual cell (membrane potential); (b) intra-vitally identified zones of brain structure with a more complex structural-functional organization as components of cortical-subcortical systems; and (c) brain systems having cortical projections on the head surface (frontal, temporal, parietal regions) made it possible to substantiate the advanced and developed concepts on the existence in the brain of cellular, supracellular, and systemic levels of integrations of ultraslow information-control systems."* The interaction among these levels and their projections to the head surface is the basis for use of the omegametry method and its determination of the functional state.

The omegametry method gives a continuous recording of the omega-potentials within the frequency band of 0 to 0.5Hz. The main parameters derived from the omegametry method estimate the initial level of active wakefulness (LAW) and the level of operative rest (LOR) which estimates the non-specific resistance of the body to stress of a given subject (74). The collective works of Ilyukhina and Sychev differentiated parameters of LOR for the assessment of the healthy subject's adaptation and compensatory-adaptive abilities in response to mental and physical loads in sports (74). The following table summarizes the levels of parameters and physiological significance (74).

Table 2. Physiological interpretations of resting omega-potential.

Mean Negative Value of Resting Omega-Potential	Functional State	Physiological Significance
-5 to -25 µV	Exhaustion	Limited adaptive ability and low functional reserve
-25 to -40µV	Optimal	Highly adaptable and efficiency of learning new habits. High functional reserve
-40 to -60µV	Tension	Pyschoemotional stress, restricted mental states, limited adaptive capability

Note. Adapted from "Ultraslow Information Control Systems in the Integration of Life Activity Processes in the Brain and Body" by V.A. Ilyukhina *Human Physiology*, *39,* p. 327.

In addition to physiological values of resting omega-potential, the time until stabilization characterized by a plateau in resting potential, was another predictor of psychoemotional tension (72). Optimally, a subject should reach stabilization in less than three minutes, indicating their ability spontaneously to relax (transition from active wakefulness to state of operative rest). However, times up to 5 and 8 minutes are characterized by moderately slow and drastically delayed relaxation respectively.

Literature supporting omegametry in sport is limited. However in the context of physiological mechanisms of adaption to physical loads, hypoxia, and other extreme environmental factors by in large induce the same non-specific resistance of the body. Recently a study examined the effects of voyage length on sailor's compensation and adaptation ability (153). The physical stress and extreme environmental factors sailors endure is quite substantial as such the use of omegametry would be warranted. The crew members of two vessels of differing travel lengths, 75 and 157 days respectively, were monitored at various stages of the journey. Results concluded that adaptation stress lasted approximately 60 days at which point decrements in compensation and adaptation were observed. Sailors on the long trip displayed signs of the exhaustive state in the general adaption syndrome, and maladaptive processes ensued(153).

The most influential publication regarding the use and efficacy of the omegametry method was provided by Ilyukhina and Zabolotskikh in 2000(76). Subjects were asked to complete two exercise bouts at a comfortable rate until exhaustion. The two groups were selected based upon tolerance levels to exercise and physiological parameters of the autonomic system, external and tissue respiration, central hemodynamics, peripheral oxygenation, acid-base and energy homeostasis, as well as adaptive responses and non-specific resistance of the body. Subjects who displayed tolerance to exercise were characterized by optimal levels of wakefulness (DC potential = 32.6 ± 8.7 mV) whereas those who fatigued quickly exhibited levels of reduced functional activity (DC potential=-12.5 ± 1.8 mV). Likewise, homeostatic parameters correlated positively with those who were tolerant to physical exercise compared to those who fatigued quickly. When the DC potential is within optimal levels, regulatory systems are more efficient in compensatory reactions to maintain homeostatic norms. Both studies exemplify the DC potential as the overall indicator of stress tolerance, characterized by compensatory responses of the regulatory systems.

The practice of sport, whether physical or technical, should be considered an activity of inducing extreme environmental conditions if correctly programmed by strength and conditioning professionals. However, the exposure to those conditions for lengthy periods can lead to overtraining, or the exhaustive state of the GAS, as was observed in sailors with prolonged voyages. The omegametry method provides strength and conditioning professionals a quick and non-invasive method of determining the functional state of an athlete. Training volumes and intensities may be altered to match the adaptive ability of the athletes and will serve to enhance their recovery, thus improving performance and reducing injury. Analysis of the psychophysiological interpretation will allow performance enhancements beyond strength and power but will also serve to indicate the psychological readiness for skill acquisition.

Heart Rate Variability

The analysis of heart rate variability (HRV) has received considerable attention over the past two decades as a viable assessment of an organism's regulatory system, specifically the functional state of the autonomic nervous system. HRV studies began in the early 1960s as part of the USSR space program (127). Their initiative was to examine the human physiological costs associated with working in extreme conditions and to apply this knowledge towards medical control of astronauts in space.

Nearly 20 years had passed before HRV studies began in the United States. Akselrod et. al were the first groups to publish in the 1981 journal *Science*, with an examination of power spectral analysis of heart rate fluctuation (3). Since that time HRV analysis has seen a growing trend of researchers from various disciplines due to its wide range of applications. In 1996, panel experts representing the European Society of Cardiology and the North American Society for Electrophysiology developed standards for the measurement, physiological interpretation, and clinical application of the methods for analyzing HRV (1).

The use of HRV analysis in sport has been extensively established in both European and North American countries (9). A recent publication from Russian authors believe the standards set forth by the European and American council in 1996 negate the 30-year history of HRV application in space medicine, physiology, and sport (10). Thus, this section will discuss the methodology and application of HRV in athletics with consideration from both Russian and American literature.

The cardiovascular system is mostly under the control of higher brain centers and the parasympathetic and sympathetic branches of the autonomic nervous system. Regulatory control is provided by afferent feedback from chemoreceptors, mechanoreceptors, and circulating hormones located in the periphery. HRV based on these regulatory mechanisms (nervous, humoral, and hormonal) is a concept of functional system theory and biological cybernetics founded by Russian scientists (8). Consistent with these theories, blood flow regulation is achieved by a central component (cortical and sub-cortical levels) and autonomic component (nervous, humoral, hormonal) with direct connections and feedback (11). By this model, heart rate fluctuations are a consequence of the dynamic interaction between systems based upon the dominant metabolic need at the time.

The autonomic nervous system (ANS) is predominately concerned with the regulation of bodily functions, such as heart rate, respiratory rate, digestion, etc. There are two divisions of the ANS, sympathetic and parasympathetic, both of which regulate heart rate. Sympathetic nerves are often associated with the "flight or fight" response, in which the heart rate speeds up and vasoconstriction ensues. Parasympathetic nerves represent the "rest and digest" statement and help to slow down heart rate. Both efferent and afferent nerve fibers are supplied to the heart with parasympathetic fibers located on the sino-atrial and anterio-ventricular nodes, and the atrial myocardium, whereas sympathetic nerve fibers are found all along the myocardium. The balance between the two systems is reflected in the beat-to-beat variability of the heart. This beat-to-beat variance is reflective of the metabolic needs of the body as it interacts with the environment. Thus, the status of the ANS and its reflection on heart rate serve as an indicator of the physiological stress on the system.

Russian scientists view the cardiovascular system as an indicator of the adaptation reactions of the whole body (11). The activation of the pituitary-adrenal system in response to a non-specific stressor, and the reaction of the sympathoadrenal system is marked by sympathetic innervation of the heart. The magnitude of innervation is indicative of tension within the regulatory systems and is an essential response to ensure adaptive processes are activated. Healthy subjects, with sufficient functional reserves, will respond to a stressor within the standard range of regulatory system tension. However, when exposure of the stressor is prolonged, adaptation reserves are depleted, and the state of exhaustion is developed. This is concurrent with Selye's general adaptation theory and its role in pathological states.

Variations in heart rate are evaluated by several methods, each with a unique representation of physiological interpretations. The time domain method serves to be the most popular in literature, possibly due to its simplicity in measurement. With this method either the heart rate at any point in time or intervals between successive standard complexes are determined. In a continuous electrocardiogram (ECG) recording each QRS is recorded. The intervals between the adjacent QRS complexes are referred to as the normal-to-normal (NN) interval and serve as the primary determinant for statistical analysis (1). The most common time domain variables include the standard deviation of NN intervals, and the root mean squared of standard deviation between NN intervals (1).

Frequency domain methods employ a spectral analysis of the tachogram (graphical record of speed and distance between NN) which describes the activity of the branches of the ANS (1). Very low-frequency (<0.04 Hz) modulation, Low-frequency (LF) modulation (0.04-0.15 Hz), and High-frequency (HF) modulation (0.15-0.4 Hz) represent the sympathetic, parasympathetic and sympathetic, and parasympathetic systems respectively (1). The final method is represented by the Poincare Plot where the NN intervals are plotted over time and standard deviation is used to interpret changes observed. The standard descriptor 1 (SD1) represents the fast beat-to-beat variability and is reflective of the parasympathetic nervous influence whereas the standard descriptor 2 (SD2) represents the longer-term variability (159) and reflects both sympathetic and parasympathetic influences.

Table 3. Primary heart rate variability parameters and physiological interpretation

Variable (abbrv.)	Designation of Variable	Physiological interpretation
SDNN	Standard Deviation of NN intervals	Total effect of ANS of autonomic regulation of blood flow
RMSSD	Square root of the sum of differences of NN intervals	Activity of the parasympathetic link of autonomic circulation
HF%	The spectral power of high-frequency modulation in % of the total power fluctuations	Relative level of activity of parasympathetic link of regulation
LF%	The spectral power of low-frequency modulation in % of the total power fluctuations	Relative level of activity of vasomotor center
VLF%	The spectral power of very low-frequency modulation in % of the total power fluctuations	Relative level of activity of sympathetic link of regulation
SD-1	Standard descriptor of fast N-N variability	Reflective of parasympathetic activity
SD-2	Standard descriptor of longer-term NN variability	Reflective of both parasympathetic and sympathetic

Numerous authors have examined the practical use of HRV analysis in diverse athletic populations (9). Unfortunately, many authors focus on endurance based sports such as long-distance running, canoeing, kayaking, and cycling where oxidative energy systems are dominant (44) (143) (20), many of which measured HRV during and immediately after a training bout. Since the focus of this literature review is on the functional state of a power athlete, which is assessed in a rested state prior to a training session, articles considered will be geared towards HRV in overreaching and overtrained athletes.

The first notable study by Chen et al. describes HRV parameters in power lifters following a heavy resistance training session (32). After a ten-day detraining period, subjects were presented with a 2 hour heavy resistance training bout consisting of back squat, seated shoulder press, dead lift, and front squat. Biochemical parameters associated with muscle damage and recovery were assessed along with subjective assessments of soreness. Results showed decrements in weightlifting performance in conjunction with increased sympathetic tone. Both weightlifting performance and parasympathetic power returned to baseline values 24 hours post exercise. DHEA levels dropped at 24 hours and returned to normal values by 48 hours post-exercise. Creatine Kinase increased significantly at 3 hour's post but returned to baseline at 48 hours post-exercise. The results of this study indicate that parasympathetic power reflects the recovery status of weightlifters. (32)

While this only represents the effect of one exercise bout on HRV parameters, it shows the typical response of the ANS following a stressor. Immediately post-exercise sympathetic power increased, representing an alarm stage for the mobilization of energy resources. Once adequate resources were allocated, and the repair process began, a shift back towards parasympathetic power was observed. In a training environment where multiple bouts are performed throughout the season, the current state of the autonomic tone can predict where an athlete is on the recovery continuum. If training loads exceed the adaptive capabilities of the athlete, it is possible to reach states of overtraining.

The application of HRV as a measure of recovery has serious potential to guide the training process on an individual basis. Tian et al. examined the training process and the effect on HRV during competition and concurrent training of elite wrestlers over a 4 year period (157). At the end of the 4-year period, it was recorded that 21% of the sample were diagnosed as non-functional overreached athletes. The overreached athletes were compared to the normal responders in both time and frequency domain HRV parameters. The results of the study concluded overreached athletes exhibited two types of changes. One was a significant decrease in HRV (sympathetic), whereas others presented an increase (parasympathetic). Clinically, two forms of overtraining have been recorded involving sympathetic and parasympathetic changes (105). The early stages of overreaching are characterized by an increase in sympathetic tone while prolonged durations of the overreached state are marked by parasympathetic tone (105). This has great relevance to Selye's GAS as excessive exercise first elicits an alarm stage (sympathetic hypertonia) and without adequate recovery the adaptive mechanisms are exhausted (parasympathetic hypertonia).

It is not uncommon for athletes to move between sympathetic and parasympathetic dominance as it reflects the body's adaptive capabilities. Tien characterized these athletes as having trends in one form of dominance for periods of two weeks or more at which point conditions become pathological. The relative contribution of both studies described outlines the short term response and long-term response to training loads. Future research will be needed to refine the use of HRV in monitoring the training process.

SPECIFIC ADAPTATION TO STRENGTH AND POWER TRAINING

The following section will discuss the specific adaptations to strength and power training as it relates to the physiological demands of American Football. Since the majority of American football is governed by anaerobic glycolysis and phosphate energy systems, this review will focus on adaptations specific to strength and power. As such the mechanisms of adaptation discussed are as follows: cellular adaptations in skeletal muscle, hypertrophy of skeletal muscle, endocrine response, and neural adaptation.

Cellular Adaptions in Skeletal Muscle

The concept of muscle converting chemical energy into mechanical work has been researched extensively throughout the century (92). This brief section will highlight the significant findings relative to the molecular contribution to increasing force and power. Muscle, in hierarchal organization, is divided into the following sub-units: Muscle fiber, myofibril, sarcomere, and protein filaments. Actin and myosin constitute the protein filaments and serve as the molecular stage for muscle contraction. During muscle contraction, cross bridges on the myosin filament bind to actin and upon hydrolyses of ATP the actin filament slides over the myosin decreasing the length of the sarcomere, i.e. muscle contraction (133). Objective measures of force output from a single cross-bridge interaction suggest that roughly 3-4 pN have been measured in isometric conditions (46). From the constructs of this experiment, muscle force is simply a reflection of the number of cross bridges working in parallel. Thus, increases in force production, and ultimately power, can be achieved through increasing the cross-sectional area of muscle fibers. A training adaptation referred to as muscle hypertrophy will be discussed in greater detail in the subsequent section of this review.

In terms of power production, force only constitutes one component of maximal power output. Power is an expression of work $(Force\ X\ Distance)$, performed per unit of time ($\frac{Force\ X\ Distance}{Time}$), since time and distance are functions of velocity, it can be concluded that work= force X velocity (92). Improvements in force production are observed with an increase in cross sectional area of muscle fibers as discussed above. Adaptations to increase velocity of shortening are contrary to increases in maximal force, where adding sarcomeres in parallel increases force, additional sarcomeres in series increases contraction velocity (92). Optimizing sarcomere length can be induced by increasing force over a large range of motion or by passively stretching muscles for an extended period of time. Many hypotheses have been proposed to explain this phenomenon each with a unique contribution of information.

The most logical conclusion was proposed by Susan Herring et.al (1984) where sarcomere length is optimized for the muscle length at which force exerted on the tendon is the greatest (65). Butterfield et al. 2005 confirmed this hypothesis while observing sarcomere adaptations of synergistic knee extensor muscles, of distinct structural architecture, exposed to extensive concentric and eccentric running protocols (26). Results revealed muscles of short fibers lengths added serial sarcomeres in eccentric running protocols but experienced a loss on concentric protocols. Conversely, muscles of long fiber length added serial sarcomeres in concentric protocols and a loss in eccentric protocols. (26). These findings are in accord with Herring illustrating local muscle adaptation is a product of the magnitudes of strain during exercise.

Beyond hypertrophic and sarcomerogenic adaptions, muscle fiber phenotypes significantly predict an individual's power output. The myosin molecule consists of two heavy chains wrapped around each other with globular heads extending out forming the cross bridge. The rate at which the cross bridge determines the maximal velocity of shortening (Vmax) for a given muscle. Cross bridges are not homogenous proteins yet exist in three isoforms expressed as MyHC-I, MyHC-IIA, and MyHC-IIX (92). Single fiber studies show Vmax is predicted based upon the given isoform. MyHC-I are slower to shorter compared to MyHC-IIA, whereas fibers expressing MyHC-IIX are the fastest and most powerful of the three isoforms (103) (22) (60) (170).

Cross-sectional data on athletes suggest world class athletes in power events have larger proportions of muscle fibers of faster fibers whereas endurance athletes express predominately slower fibers (36) (135). Although genetic factors largely determine the ratio of isoforms present in the composition of an individual's muscle, specific training type has been shown to alter ratios of isoforms expressed. A host of studies have shown both endurance and strength training predominately increase the proportion of MyHC-IIA isoform expression at the expense of MyHC-IIX without decrement of MyHC-1 (60) (5).

Adaptation occurring at the molecular level, in respect to increasing strength and power, are largely determined by the cross-sectional area of muscle fiber, muscle length and velocity of shortening, and the proportion of myosin heavy chain isoforms. Of those variables, cross-sectional area of muscle seems to be the most influential and trainable. The proportion of muscle fiber phenotypes is highly genetic, and proportions of such are the largest determinant of success within a given sport.

Hypertrophy of skeletal muscle

Skeletal muscle is a very adaptable tissue in response to different types of training loads. Two kinds of adaptations are present with regards to athletic training, increased force and power as seen in resistance training, and increased repeated contraction as seen in endurance training. As mentioned above, hypertrophy of muscle fibers is the most trainable of molecular factors, as genetics predominately predicts ratios of muscle fiber phenotypes. Consequently, training regimes are designed to focus on hypertrophic adaptation. As this review is concerned with strength and power, the focus of this section will address the physiological mechanisms of hypertrophy and its subsequent impact on force generation.

It is has been well established that bouts of resistance training elicit increases in cross-sectional area of muscle fibers. Following a training session, an increase myofibrillar protein synthesis is observed (33) peaking at 24 hours with elevations observed for 36-48 hours post training (109) (132). In a structured training program with repeated bouts of resistance training, protein synthesis facilitates an increase in myofibrillar number and subsequently myofibrillar area. The process by which this occurs is thought to be the product of longitudinal splitting of myofibrils (51). The splitting may be a result of connective tissue rupture of the Z-disk produced by repeated forceful contractions resulting in two or more daughter myofibrils (52).

Recent literature suggests that longitudinal splitting may not be the predominant mechanism for muscle hypertrophy and that satellite cells are responsible for the increases observed (83). Satellite cells are activated in response to hypertrophic training loads and serve to provide myonuclei to muscle fibers as they increase in size or length.

In addition to donating nuclei, satellite cells are responsible for the repair of damaged and necrotic muscle tissue. Upon traumatic injury to the muscle fiber, satellite cells undergo mitotic proliferation and expand across the length of the damaged fiber. Once inside the cell, they differentiate to repair the damage by forming new myofibrils (30).

Many factors determine an individual's ability to increase cross-sectional area of muscle, predominantly genetic factors. Additional factors consider the type, intensity, and duration of the training program along with the training status of the individual. For strength and power athletes, muscular hypertrophy is a predominant training goal. As mentioned above, increasing force through muscular hypertrophy is one the most significant and trainable factors for power development at the muscular level.

Endocrine Response & Adaptation

Strength and power training impose a strong stimulus and disruption of the homeostatic parameters to the musculoskeletal system. This stress cascades a multitude of physiological responses and subsequent adaptations to increase muscular strength, power, and hypertrophy as a product of resistance training (99). One of the most significant physiological systems involved in the adaptation response is the neuroendocrine system. A variety of hormones are responsible for the tissue repair and remodeling mechanisms following a bout of heavy resistance training which are crucial to strength and power development. The hormonal response discussed in the section will focus on anabolic hormones that are relevant to skeletal muscle repair and restoration.

A multitude of resistance training variables have been identified as influential factors determining the acute and chronic endocrine response and subsequent adaptation

(94) (117) (99). These variables include: exercise selection and order, muscle contraction action (eccentric vs. concentric), intensity, volume, rest periods between sets, frequency, and muscle groups trained. These variables have a profound impact on metabolic, neural, muscular, and cardiovascular systems which interact with the endocrine system to achieve adaptation useful for the athlete.

Carefully designed resistance training programs will alter the variables listed above to achieve maximal neuromuscular adaptations. Three crucial training principles must be applied to ensure the appropriate stimulus is applied to elicit a hormonal response. The overload principle warrants adaptation to occur by applying a training load greater than what the system is adapted to. Once the system has adapted, an increase in training load must be used to challenge the newly acquired fitness level (principle of progression). Finally, the principle of specificity must be considered to provide adaptation specific to the desired outcome. If these conditions are present within the program design, homeostatic disturbance of muscle will ensue and elicit the consequent hormonal response.

The majority of research to date has focused on measurement of circulating blood hormone levels following a resistance training bout with the assumption that acute increases present a greater possibility of hormone utilization. Hormonal concentrations and ensuing interactions within blood and muscle tissue are mediated by several mechanisms. These factors include shifts in blood volume, changes in extrahepatic clearance rates, changes in hepatic clearance rates, hormonal degradation, venous pooling of blood, and receptor interactions (79) (93). The collaboration of these variables may be involved in up-regulating receptor sites for hormonal interaction, increasing the probability for optimal tissue remodeling.

Steroid hormones are of particular interest to researchers due to their highly anabolic nature. A host of studies have shown an acute increase of blood testosterone concentration in response to resistance training (169) (31) (66) (101) (97). It has been suggested that increases testosterone synthesis and secretory capacity of the Leydig cells may be responsible for observed elevations (49). Additional research has shown decrements in the sex hormone-binding globulin (SHBG) with no change or a slight increase in testosterone concentration (59). Since unbound free testosterone represents the biologically active hormone, a decrement in SHBG with no change in total testosterone level indicates a potential beneficial adaptation to resistance training (99).

Several factors regarding program design appear to influence acute testosterone concentration following a resistance training bout. The degree of which have been shown to be affected by muscle mass involved (168), exercise selection (168), intensity and volume (98), nutrition intake (99), and training experience (97).

Exercise selection incorporating movements requiring large muscle mass groups such as dead lift and squat have been shown to elicit significant elevations in testosterone (93). When comparing testosterone response from upper and lower body exercised, Volek et al. reported significantly higher acute testosterone responses from jump squats versus bench press (15% and 7% respectively)(167). It has been suggested the difference is due to the metabolic stress accumulated when involving larger muscle groups (100), thus a robust metabolic stimulus has been suggested as a precursor for testosterone release (107).

Alterations of intensity and volume in resistance training programming have also been shown to affect testosterone release. Weiss et al. reported a significant increase in serum testosterone following 3 sets of 10RM with a one-minute recovery produced higher concentrations than one set of 10RM (169). Raastad et al. found more elevated serum testosterone in a high-intensity group (100% of 3-6 RM) versus a moderate intensity group (70% of 3-6 RM) (137). Schwab et al. compared a protocol of 4 x 6 (90-95% of 6RM) to 4 x 9 (60-65% of load used for high-intensity protocol) for the squat and observed similar increases in serum testosterone from both protocols. However, this increase was not significant until after the fourth set indicating that a certain threshold of volume must be obtained to elicit testosterone release (148). Several authors attribute the glycolytic demands of high volume/moderate intensity training as a signaling mechanism for testosterone release (98). This hypothesis would also coincide with the assumption that glycolytic activities present opportunities for pronounced metabolic demands as mentioned above. In regard to chronic changes in testosterone, limited evidence has been presented to support it. However, several studies have shown an up-regulation of androgen receptors in response to long-term resistance training (12) (42). Their results show beneficial adaptation at the cellular level providing greater opportunities for hormone receptor interaction and subsequent protein synthesis.

Growth hormone (GH), like testosterone, has been shown to provide an anabolic response in conjunction with resistance training. Similar to testosterone, GH has been shown to increase during resistance exercise up to 30 minutes post exercise with the magnitude reflective of exercise selection (93), intensity (158), volume (58) (21), rest periods between sets (98), and carbohydrate/protein supplementation (31). As seen with acute testosterone release, training programs which employ a moderate to high intensity, high volume approach observes the largest acute GH response (122) (38). Interestingly studies which examined the lactate response to resistance training observed H^+ accumulation by lactic acidosis was positively correlated with GH release (95). Additionally, hypoxia, breath holding, acid-base shifts, and protein catabolism have all been reported to promote GH release (95). Thus, supporting the assumption that high metabolic demands of strength training are necessary to increase anabolic hormone concentrations.

Neural Adaptation

Up to this point in the literature review, increases in strength and power from muscular adaptations have been discussed. Of those adaptions discussed, increasing cross-sectional area of muscle fibers was proposed to be the largest and most trainable determinant of increased performance. This statement is true concerning local muscular adaptations, however neural adaptations have a profound impact on performance improvements especially with regards to power output. This section will discuss the variety of neural training adaptations, specifically motor unit recruitment of agonist muscles, synergist activation, and inhibition of antagonists.

The most significant neural adaption to consider is increased motor unit activation of agonist muscles. Increases in neural activation can manifest in three ways: consistent recruitment of high threshold motor units, increased firing rate for strength, and increased firing rate for force development. In accordance with Henneman’s size principle, the highest threshold motor units would consist of the larger Type-II muscle fibers, capable of producing more significant amounts of force (63). In addition to the recruitment of high threshold motor units, the firing rate becomes influential on force production and the rate of force development. Studies indicate that following a strength training intervention, subjects will increase the frequency at which they recruit maximal motor units. This allows muscle fibers to operate further on the force-frequency curve, producing more considerable force outputs (45). In separate studies, initial firing rate was observed to be higher at the conclusion of a training intervention (171). While maximal force output was unchanged, the rate of force development was significantly higher than pre-test measurements.

When developing a new skill, or in the realm of this discussion, a new resistance training exercise, the recruitment of synergist muscles will largely determine the outcome. For simplicity, synergist muscles will be defined as a group of agonist muscles that work together to perform an action. The coordination of synergists muscle groups will allow for the greatest amount of force to be applied in a given direction and velocity. Studies suggest that training enhances coordination by neural adaption and has been demonstrated in the specificity of the training response. Specificity may be related to the movement pattern, type of muscle contraction, and speed at which change occurred (144). A host of studies indicate larger strength gains are observed in subjects whose strength test was specific to the types of movements employed during training and lower when the strength test was non-specific (142) (141). This has a considerable impact when selecting exercises for a sport with specific movement patterns.

Finally, the inhibition of antagonist muscles must be taken into consideration for strength gains observed from strength training. It may seem counter-intuitive for co-contraction of agonist/antagonist to be part of our physiological design because opposing force developed by antagonist would reduce the net force of the intended movement. However, studies have shown that co-activation of antagonist muscles serve to maintain joint stability in high velocity or high force movements (35). Resistance training has been shown to reduce the influence of antagonist muscles on net force output. Two patterns of results have emerged from these studies: first a decrease in the absolute antagonist activation along with an increase (57) or no change in agonist activation (28); secondly, the unchanged antagonist activation, but an increase in total agonist activation, therefore decreasing the antagonist/antagonist activation ratio (34).

The total contribution of neural adaptation versus muscle adaptation is not precise. However, it has been documented in many studies that neural adaptation proceeds muscular hypertrophy which explains the rapid increase in strength from a novice weightlifter within the first 4-6 weeks (145). When dealing with experienced athletes, neural contributions to strength and power gains may play a reduced role. This does not imply that strength training is unnecessary for experienced lifters as the maintenance of neural drive is vitally important for the preservation of strength.

Summary

The adaptive capabilities of the human organism are immense when taking all environmental stressors into consideration. Adaptation specific to power and strength training represent the collaborative effort of inter-system communication between organs and tissues to achieve a more resilient athlete to repeated stressors. It is essential that appropriate means are taken to ensure the training process is guided by measures of physiological readiness or functional states so that ideal volumes and intensities are prescribed to secure optimal performance outcomes.

Based upon an extensive literature review, the DC potential and HRV prove to be a valid assessment of the functional states of athletes. The DC potential is a precise, reliable, and reproducible method for evaluating the functional state of the body. This method has been validated in physiology and medical science for over 70 years. The DC potential method can be utilized in sport by assessing the functional state and adaptation changes occurring in response to training loads.

Heart rate variability analysis is a proven scientific method utilized in physiology, medicine, and sport as an assessment of the functional state of the cardiovascular system. Throughout its 50-year history, HRV analysis has demonstrated its effectiveness in the evaluation of adaptive responses of the cardiovascular system to loads. This method can be used for evaluating the athlete’s functional state, predicting overreaching and overtraining, and most importantly it serves to guide the training process.

CHAPTER III

METHODS

Experimental Design

The purpose of this study was to evaluate the effect of fluid periodization models on athletic performance outcomes in D-1 American football players. Models were dictated by the assessment of the athlete's functional state as indicated by the Omegawave readiness output (Omegawave Ltd, Espoo, Finland). The experimental design of the study utilized a longitudinal comparison between two non-randomized groups. Subjects were sorted into treatment or control groups under the discretion of the coaching staff based on position and year in the program. The treatment group adhered to a fluid periodization model in which volume or intensities of exercise sessions were modified based upon Omegawave's assessment of the athlete's functional state. The control group was not assessed with the Omegawave AMS and adhered to a similar block periodization regimen as planned by the Strength and Conditioning Staff. The utilization of fluid periodization served as the independent variable. The dependent variables included anthropometric measures (mass, relative body fat, fat mass, and fat free mass), performance outcome tests (broad jump, vertical jump, triple broad jump, 10 lb. medicine ball overhead throw, tempo test), and total volume of loads.

Subjects

A convenience sample of 59 D-1 American football players were recruited to participate in this study. To qualify, subjects must have been a current member of the University's football team and cleared to participate in a resistance training program without restrictions. All subjects completed a medical examination as required by the

University for participation in varsity sports. All subjects provided written informed consent after a detailed explanation of the study's aims, benefits, and risks were provided. Additionally, subjects were informed that their participation would not affect their status on the team and that they were free to withdraw from the study at any time without penalty.

Table 4 displays the Chi-square crosstab calculation between academic classification and experimental groups. A Pearson Chi-Square calculation (α=0.498) indicates that there is not a difference between the distribution of subjects by academic classification in the control or experimental groups.

Table 4. Number and relative distribution of subjects by academic classification within experimental and control groups.

			YEAR				**Total**
			Freshman	Sophomore	Junior	Senior	
GROUP	CTL	Count	2	12	6	8	28
		% within YEAR	33.3%	60.0%	37.5%	47.1%	47.5%
	EXP	Count	4	8	10	9	31
		% within YEAR	66.7%	40.0%	62.5%	52.9%	52.5%

*Pearson Chi-Square α= 0.498

Procedures

A total of four testing sessions were utilized for baseline and posttest measures. Performance outcome measures were selected based upon the biomotor abilities required for the sport of American football. These abilities include lower body power, total body power, and aerobic capacity. Performance outcome measures included vertical jump, broad jump, triple broad jump, 4.55 kg overhead medicine ball throw, and tempo test. Anthropometric measures included height, body mass, relative body fat, fat mass, and fat-free mass. The first session included baseline measurements of power performance outcomes and anthropometric measures of all subjects. The order of tests were as follows: anthropometric measures, vertical jump, broad jump, triple broad jump, and overhead medicine ball throw. A 5 minute rest was provided between each power exercise to minimize fatigue. The second testing session occurred following a two day recovery period and included the aerobic tempo test. Posttests occurred in the same sequence following a ten day active recovery period. Total load volumes were reported throughout the training period. All testing sessions took place at the University's training facility. Resistance training volumes were calculated by the product of repetitions, sets, and % of 1 repetition maximum (RM) for core lifts and accessory lifts. Conditioning volumes for non-weight room training sessions were calculated by session ratings of perceived exertion (sRPE), in which each athlete provided a subjective rating of perceived exertion using a modified Borg scale (110). An arbitrary training load was calculated by taking the product of the sRPE and the training session time in minutes. For example, if an athlete rated a 100 minute training session as a 5 then a 500 arbitrary unit (AU; 5 sRPE x 100 min = 500 units) training load was recorded. This method has been shown to be valid in athletic populations including soccer (53) and rugby (48).

Prior to performance assessments, anthropometric measurements of height, body mass, fat mass, and fat-free mass were recorded. First, standing height was measured without shoes (to the nearest 0.1cm) using a portable stadiometer (Road Rod 214 Seca, Hanover, MD, USA). Body mass and body composition were measured via air displacement plethysmography (BOD POD, COSMED, Albano Laziale, Italy). The device was calibrated according to manufacturer's instructions prior to each testing session with long volume being estimated rather than measured. The subjects relative body fat percentage was calculated (to the nearest 0.1%) using the manufacturer's prediction equation.

Lower body power was assessed by measuring vertical jump height. The test-retest reliability of this assessment in this sample was r = .96. Results were normalized by weight using the Lewis equation (125) to assess peak power output. Jump height was measured (to the nearest 1.27 cm) by the Vertec (Vertec Sports Imports; Hilliard, OH, USA) measuring device. Standing reach height was recorded using a two hand outreach with the feet positioned flat on the ground. The difference between jump height and standing height was used to determine vertical jump height. After proper warm ups, athletes performed a counter movement jump reaching with their dominant hand toward the highest vane on the Vertec system. Each athlete performed three jump trials and the average of the trials was used in the data analysis.

Total body power was measured by the 4.55 kg overhead medicine ball throw test. The test-retest reliability of this test in this sample was r = 0.95. Furthermore this test has been shown to be a valid (0.903) and reliable (0.996) measure of total body explosive power when compared to the counter movement vertical jump (55). Subjects stood with feet parallel, and facing the opposite direction in which the ball was thrown. The ball was held with hands on the side and slightly behind the ball. The subject fully extended the knees and hips while bringing the ball above the head. In a swift motion the subject began a counter movement, bringing the ball between the legs. An explosive triple extension of the ankle, knee, and hip occurred and the athlete released the ball overhead. Throwing distance was measured in meters (to the nearest 0.1 m) between the line in which the throw was initiated to the spot the ball landed. Three attempts were performed and the maximum value was used in the data analysis.

Aerobic capacity was evaluated by a custom designed tempo test. The tempo test consisted of 10 submaximal sprints that were separated by 30 seconds of recovery. The sprints were performed at 75% of the athlete's perceived maximal effort. Sprint distances were position specific with lineman covering 40 yards in 6 seconds, linebackers, tight ends, quarterbacks, and kickers covering 60 yards in 7 seconds, and wide receivers, running backs, and defensive backs covering 80 yards in 8 seconds. All athletes covered the distance within the allotted time without any sign of distress. Heart rate was measured with telemetry and recorded by the Catapult athlete tracking system (Optimeye S5, Catapult Sports Melbourne, AUS). Heart rate was recorded one minute posttest. Heart rate data were exported to excel and improvements in aerobic capacity were evaluated by the one-minute heart rate recovery.

Omegawave Testing Protocol

Omegawave Ltd. software and hardware were used to provide assessments of physiological readiness to the treatment group prior to each training session. This technology assesses both the readiness of the central nervous and cardiovascular systems through direct current (DC) potential analysis and heart rate variability analysis (HRV), respectively. To administer the assessment athletes followed the standard protocol according to Omegawave. Optimally, assessments occurred within thirty minutes of waking, thus subjects in the treatment group self-administered their readiness assessment. Athletes were instructed that testing conditions should be conducted in a calm and quiet environment. Intake of food or caffeine substances prior to testing was discouraged to prevent any disruption in autonomic tone. Prior to measurement period athletes were instructed to remain vertical for at least one minute before placing themselves in a relaxed supine position. Upon lying in a supine position, athletes were to wait two minutes before taking the measurement. HRV and DC potential data were collected on the athlete's personal device via Bluetooth transmission. Once the measurement was completed, data from the athlete's device was uploaded to Omegawave's cloud server where the raw data were analyzed and interpreted. Once all the athletes completed their assessment the analyzed data were downloaded directly to the investigator's laptop computer where interpretation and volume adjustments were determined. The subjects average daily compliance rate to taking these measurements was 83%. Prior to the initiation of the study all athletes received an instructional demonstration of the assessment protocol.

The readiness of the cardiac system was provided by the interpretation of HRV. During it's over fifty-year history, HRV analysis has provided professionals with the analysis of the functional state of the cardiac system and the autonomic influences acting upon it. Omegawave analyzes ten parameters of HRV which are in accordance with the Standard Registration and Physiological Interpretation for Clinical Use, as defined by the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1). In addition to those standards, Omegawave analyzes an additional five parameters used in Russian space medicine and sport (11). A comprehensive analysis of HRV and proprietary algorithms allow for conclusions on the levels of stress, fatigue, and adaptation reserves of the athlete. The combination of these variables contributes to the overall state of the cardiac system and its ability to regulate blood flow. The following table outlines the parameters provided by the Omegawave AMS.

Table 5. Omegawave parameter definitions, abbreviations, and units.

Variable Name	Definition	Abbreviation	Units
Stress Index	The level of tension in the cardiac system in response to physical and mental loads	SI	Relative/7
Fatigue	The temporary state of the cardiac system that occurs during prolonged work that leads to a decrease in the effectiveness of the work	FT	Relative/7
Adaptation Reserves	A measure of how long and effectively the cardiac system can express the ability to adapt to external stimuli	AR	Relative/7
Activity of Vagus Regulatory Mechanisms	Indicates the current activation level of the parasympathetic nervous system's regulation of the cardiac system, which serves to maintain homeostasis and restore the functionality of the body after load	AVRM	Sec
Activity of Sympathetic Regulatory Mechanisms	Indicates the current activation level of the sympathetic nervous system's regulation of the cardiac system.	ASRM	%
Tension Index	The level of tension in the cardiac system in response to physical and mental loads. Reflects the level of centralization of heart rhythm regulation. Centralization involves increased involvement of central levels of regulation and a decreased level of autonomic regulation of heart rhythm.	TI	Relative
Standard Deviation of the Aspirate Waves	Reflects the level of automatization of heart rhythm regulation. Automatization involves a predominance of autonomic regulation and a decreased responsibility of central levels of regulation.	SDAW	Relative
Share of the Aperiodic Influences	Reflects the level of random and aperiodic activity that influences heart rhythm. Slow waves reflect activation of the central circuit and a predominance of activity in the cardio-stimulatory center (which is part of the medulla). Ex: over-trained athletes express slow waves in a significant manner.	SAI	Sec
Standard Deviation Normal to Normal	Standard deviation of the full array of cardio intervals. Reflects the total effect of autonomic regulation.	SDNN	ms

Table 5, continued.

Standard Deviation of Successive Differences	Standard deviation of differences between adjacent normal to normal intervals.	SDSD	ms
Root of the Mean Square of the Difference of Successive Intervals	The square root of the sum of differences of a sequential series of cardiointervals. Reflects the parasympathetic activity.	RMSSD	ms
Total Power	Variance of all normal-to-normal intervals, ≤0.4 Hz. Reflects the level of activity of regulatory system.	TP	ms2
Low Frequency/High Frequency Ratio	Ratio between low and high frequency components. Reflects the Sympathetic-Parasympathetic Balance. Ratio LF [ms2] / HF [ms2]	LF/HF	….
High Frequency	Power in high frequency range 0•15–0•4 Hz. Reflects the parasympathetic activity.	HF	ms2
High Frequency (Normalized Units)	LF power in normalised units LF/(Total Power–VLF) x 100, n.u.	HF n.u.	Normalized Units
Low Frequency	Power in low frequency range 0•04–0•15 Hz. Reflects the sympathetic activity.	LF	ms2
Low Frequency (Normalized Units)	LF power in normalised units LF/(Total Power–VLF) x 100, n.u.	LF n.u.	Normalized Units
Very Low Frequency	Power in very low frequency range ≤0•04 Hz. Reflects the humoral activity.	VLF	ms2

The readiness of the CNS was provided by the interpretation of DC potential activity. The DC potential is a measurement of brain biopotentials occurring within the frequency range of 0.0-0.5 Hz and is thought to provide a global representation of the functional state of the human organism (73). Although many methods exist to measure DC potentials, Omegawave technology uses the vertex/thenar data collection method developed by Illyukina and colleagues (73). The same group of authors established the following parameters as an overall indicator of the CNS readiness: levels of activation, wakefulness, functionality, excitation, and tonus of the CNS. To measure DC potentials, athletes placed Ag/AgCl electrodes on the vertex area of head and thenar area of the dominant hand. The measurement took approximately 2.5-5 minutes and provided information regarding basic indicators of stress level, resistance, adaptation changes, compensation abilities, cost of adaptation, and adaptability in general (47). Please refer to the literature review for interpretation of the DC potential measurements.

Resistance Training Protocol

The 8 week training intervention utilized block periodization and covered two training mesocycles in the pre-season. The mesocycles included three developmental weeks, followed by a de-load week. Programmed workouts applied to both the treatment and control groups, however, individuals in the treatment group received modified intensities or volumes based on their functional state of readiness. These modifications included resistance training exercises, Olympic lifts, and other high central nervous system (CNS) activities (e.g., Sprints > 95% of maximal effort and Explosive Jumps), were altered. Each athlete had their own prescribed workout card upon which adjustments were recorded by the strength staff.

Based on the HRV and DC potential assessment an overall athlete readiness classification was assigned. This classification is represented by three colors consistent with a hierarchal stop light interpretation approach. Athletes classified as green could participate in any activity without restriction. Athletes classified as yellow reflected one of the regulatory systems, HRV or DC Potential, was operating at a reduced level. Athletes classified as red would seek active rest or medical attention. Changes made to an individual's workouts were recorded so volumes of workloads could be adjusted accordingly. At this time, standard reductions in volumes and intensities could not be established due to the innovative approach of this study. Therefore, the magnitude of reductions in volume and intensity were determined by the strength coach based upon his expertise and knowledge of program modification. Although the reductions in training intensity and volume are reported in the results section, future research and continued evaluation of these methods in American Football will allow standardized protocols in fluid periodization as part of the athlete monitoring process.

The training emphasis for the first training block was position specific. The offensive and defensive line, linebackers, tight ends, and fullback trained predominately for strength, stimulating hormonal adaptations and protein synthesis. Wide receivers, running backs, and defensive backs trained predominately for power and speed adaptations. The weekly schedule followed a high/low CNS schedule, in which a high CNS component day was followed by a low CNS component day. For example, if Monday consisted of sprints > 95% effort, and weights > 80% effort, then Tuesday was either active recovery or extensive aerobic in nature. The following table illustrates an example of a typical week in both training blocks.

Table 4. Example of high/low CNS weekly schedule.

DAY	Monday	Tuesday	Wednesday	Thursday	Friday
Typical Exercises	Routes w/ QB Sprints Accelerative Jumps Explosive Med Ball Olympic Lifts >80%	Positional Tempo Extensive Med Ball Abdominal Circuit	Sprints Elastic/Reactive Jumps Med Ball Throws Squat >85%	Bike Tempo Massage	Routes w/ QB Sprints Accelerative Jumps Explosive Med Ball Olympic Lifts >80%

The second training block focused on the development of both alactic and aerobic capacities for all positions. The same high/low CNS training principle applied for daily programming. Position specific skill work was added and was considered high CNS stimulating in addition to resistance training activities. Outcome measures occurred approximately ten days following the second training block to allow for maximal adaptions.

Statistics

Basic statistics (mean ± standard deviation) were used to describe demographics and outcome variables. A power analysis was conducted to estimate an appropriate sample size. The power analysis was based on data from a similar training intervention (126), which examined differences in strength gains between traditional periodization versus block periodization strategies. The reported effect size in that study was 0.437 (α set at 0.05). To achieve the same effect in this study, effect size was set to 0.437, power at 0.8, and α equal to 0.05. From the power analysis, based on a matched pair t-test, a sample size of 34 subjects would be required. However, a more conservative approach must be taken due to the variance introduced by a mixed factor repeated measures ANOVA, thus additional subjects were required to achieve the desired power.

Mixed factor repeated measures ANOVA (group x time) were used to determine if differences existed in performance outcomes within or between groups and t-tests were used to determine if differences existed between groups in total training volume. Relative changes in baseline performance and anthropometric measures versus post-intervention measures were calculated as follows: percent difference = ([post-intervention measure – baseline measure] / baseline measure) x 100. Effect sizes for the change in performance, anthropometric measures, and volumes, were calculated as the absolute value of: ([$\text{mean}_{\text{basline}}$ – $\text{mean}_{\text{exercise}}$] / pooled SD). Effect sizes were defined as small, medium, and large and are represented by Cohen's d of 0.2, 0.5, and 0.8, respectively.

Efficiency scores were calculated to represent changes in performance outcomes in relation to total volumes of load and is calculated as follows: (([post-intervention measure – baseline measure]/baseline measure)/total volume). T-tests were used to determine if differences existed between groups in efficiency scores. Standard difference scores (SDS) were calculated for each individual ([individual change score - mean change score]/SD of difference scores). A composite z-score, an average of all the performance outcomes SDS, were plotted for each athlete on a modified Bland-Altman plot. This method has been shown to be useful for identifying trends in performance among a group of athletes (131). The level of significance was set at $p < 0.05$ for all statistical analyses.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The following results represent the comparative analysis between experimental groups. The results from the mixed factor repeated measures ANOVA are represented in Table 7 and address the first hypothesis confirming that the treatment group improved significantly in performance outcomes. Table 8 addresses the second hypothesis confirming that the treatment group trained at significantly reduced core and accessory resistance training volumes. The remainder of the results graphically display the effect sizes within and between groups, an aerobic efficiency comparison between groups, efficiency scores between groups, and a modified Bland-Altman plot to illustrate the overall performance between experimental groups.

Results

As a result of using the AMS in the treatment group, the training load for 28% of the total athlete exercise sessions were modified. Table 7 displays the comparison of baseline anthropometric and performance outcomes between treatment and control groups in a sample of collegiate American football athletes. No statistical difference was observed between groups in any of the outcome measures at baseline. The treatment group significantly increased in vertical jump, lower body vertical power, broad jump, and aerobic efficiency ($p < 0.001$). There were no significant differences between groups in body mass, relative body fat, fat mass, fat-free mass, triple broad jump, and medicine ball overhead throw. Significant effect sizes between groups were observed with improvements in fat-free mass, vertical, vertical power, broad jump, triple broad jump, medicine ball overhead throw, and aerobic effeciency. Large effect sizes and percent differences were observed in vertical jump (Relative difference = 157%, ES = 1.02), vertical power (Relative difference = 94%, ES = 0.86), broad jump (Relative difference = 592%, ES = 0.81) and aerobic efficiency (Relative difference = 156%, ES = 1.01) A moderate effect size was observed in the triple broad jump (Relative difference 338%, ES = 0.63), and small effect sizes were observed in fat-free mass (Relative difference = 54%, ES = 0.30) and medicine ball overhead throw (Relative difference = 50%, ES = 0.26).

Table 7. Comparison of anthropometric and performance outcomes between experimental groups in 59 American football players.

	Control (n=28)							Experimental (n=31)										
	Pre-Test Mean	±	SD	Post-Test Mean	±	SD	Absolute Difference	Pre-Test Mean	±	SD	Post-Test Mean		SD	Absolute Difference	% Difference	Effect Size	P-Value	Power
Weight (kg)	108.44	±	23.51	110.54	±	22.99	2.10	105.18	±	22.49	107.46	±	22.25	2.29	9%	0.05	0.36	0.06
Body Fat (%)	17.34	±	6.70	18.11	±	6.32	0.76	15.30	±	6.54	15.79	±	7.60	0.49	-36%	0.12	0.65	0.07
Fat Mass (kg)	20.85	±	12.98	21.83	±	12.48	0.98	17.00	±	10.35	17.70	±	11.22	0.70	-29%	0.11	0.40	0.07
Fat-Free Mass (kg)	87.03	±	12.64	88.14	±	12.58	1.11	85.98	±	13.40	87.69	±	15.41	1.71	54%	0.30	0.69	0.20
Vertical (cm)	73.21	±	8.77	75.16	±	9.63	1.95	76.86	±	9.61	81.86	±	8.74	5.01	157%	1.02	0.001†	0.97
Vertical Power (W)	7125.66	±	1215.49	7335.58	±	1214.77	209.92	7374.59	±	976.43	7782.10	±	937.07	407.50	94%	0.86	0.001†	0.90
Broad Jump (cm)	265.27	±	26.43	266.87	±	24.05	1.60	275.33	±	21.07	286.38	±	20.08	11.05	592%	0.81	0.001†	0.86
Triple Broad Jump (cm)	893.30	±	42.73	889.85	±	45.40	-3.46	895.81	±	37.05	904.03	±	38.31	8.22	338%	0.63	0.18	0.35
Medicine Ball OH Throw (cm)	1707.47	±	172.83	1655.40	±	151.98	-52.07	1807.32	±	165.06	1781.39	±	174.02	-25.93	50%	0.26	0.60	0.19
Aerobic Effeciency (bpm)	21.29	±	16.22	31.04	±	13.40	9.75	18.21	±	15.45	43.20	±	18.60	24.99	156%	1.01	0.001†	0.91

† = significant difference at p=<0.01.

% Difference = ((Absolute Difference Experimental – Absolute Difference Control)/Absolute Difference Control).

Effect Size = (Absolute Difference Experimental – Absolute Difference Control)/Pooled SD).

P-Value = significance value of the interaction effect (group x time).

Power = reported power from mixed factor repeated measures ANOVA.

Table 8 displays the accumulated core resistance training volume, accessory resistance training volume and running volume between groups. Significant reductions in core and accessory resistance training volume were observed ($P < 0.01$). No significant differences were observed between groups in running volume. The control group accumulated 2000 more arbitrary units (relative difference: +9.5%) of core resistance training volume and performed 191 more reps (relative difference: +13.2%) of accessory volume. Large effect sizes were observed for core (ES = 1.20) and accessory training volume (ES = 1.14).

Table 8. Comparison of resistance training and running volume between experimental and control groups in 59 American football players.

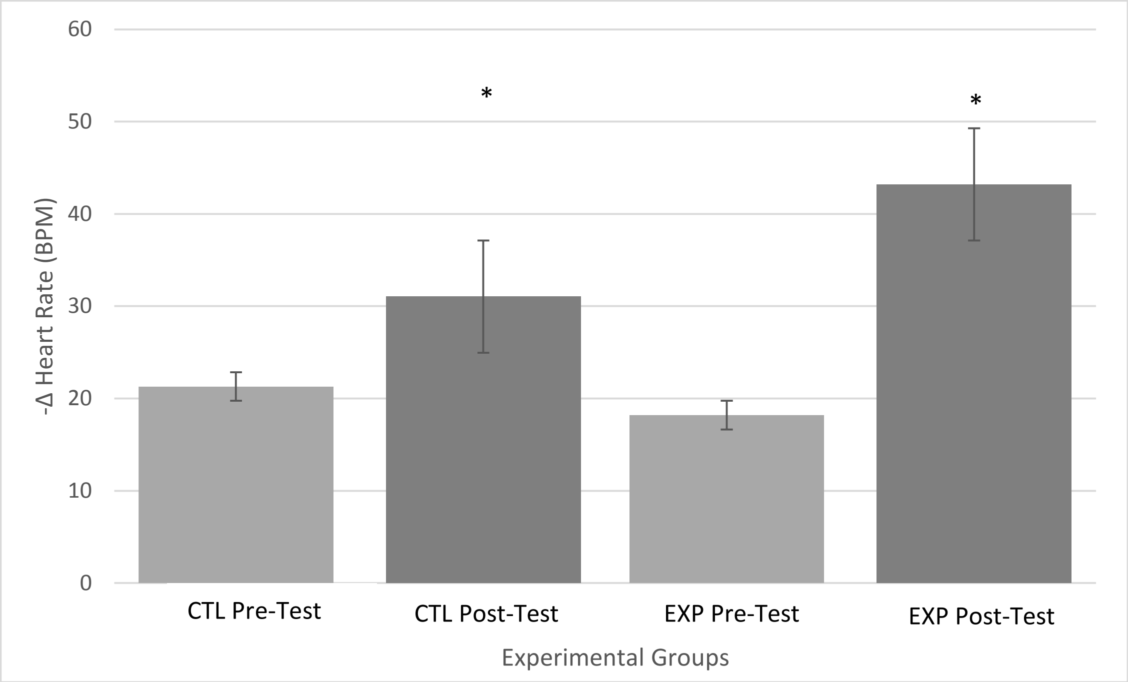
	Control (n=28)	Experimental (n=31)	Absolute Difference	% Difference	Effect Size	P-Value	Power
Core Volume*	22078 ± 550	20078 ± 2717	-2000	-9.50%	1.20	<0.01	0.94
Accessory* Volume	10815 ± 365	9478 ± 754	-1337	-13.21%	1.14	<0.01	0.92
Running Volume* (sRPE AU)	12493 ± 1243	12859 ± 1583	366	2.88%	0.19	0.33	0.28

*Core & Accessory Volume = Number of repetitions * number of sets * percentage of 1 repetition maximum

*sRPE AU = session rating of perceived exertion arbitrary unit (sRPE * total training time)

Figure 2 displays the baseline and posttest aerobic efficiency difference between experimental groups. No significant differences in pretest heart rate recovery measures were observed between groups. However, the experimental group improved heart rate recovery at posttest compared to the control group (P = .002).

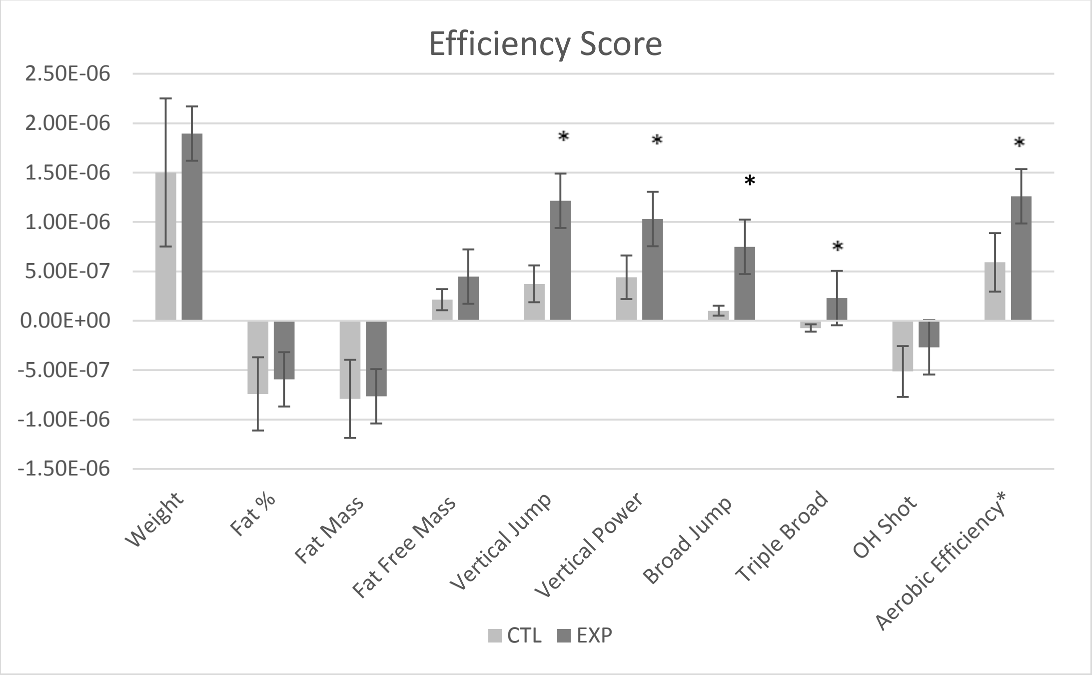
Figure 2. Comparison of aerobic efficiency between experimental and control groups in 59 American football players.



*Indicates significant within group difference ($p < 0.01$) Error bars represent standard deviation.

Figure 3 displays the efficiency scored on performance and anthropometric outcomes between the groups. The experimental group improved in body mass, fat free mass, vertical jump, broad jump, and triple broad jump and while achieving a lower body fat percentage and fat mass per unit of volume. While both groups experienced lower overhead shot scores, the experimental group showed less of a decrement compared to the control group.

Figure 3. Comparison of efficiency scores (mean ± SD) on anthropometric and performance outcomes between experimental and control groups in 59 American football players.



*Aerobic efficiency scaled by 50%.

*Indicates significant within group difference ($p < 0.01$).

Figure 4 displays the performance outcome effect sizes within and between experimental groups. The experimental group experienced meaningful effect sizes on all performance outcomes with the exception of overhead throw. When comparing the between group effect sizes, large effect sizes were observed in vertical jump, vertical power, broad jump, and aerobic efficiency. A moderate effect size was observed with triple broad jump and small effect sizes were observed with overhead throw and fat free mass.

Figure 4. Comparison of performance outcome effect sizes within and between experimental groups in 59 American football players.

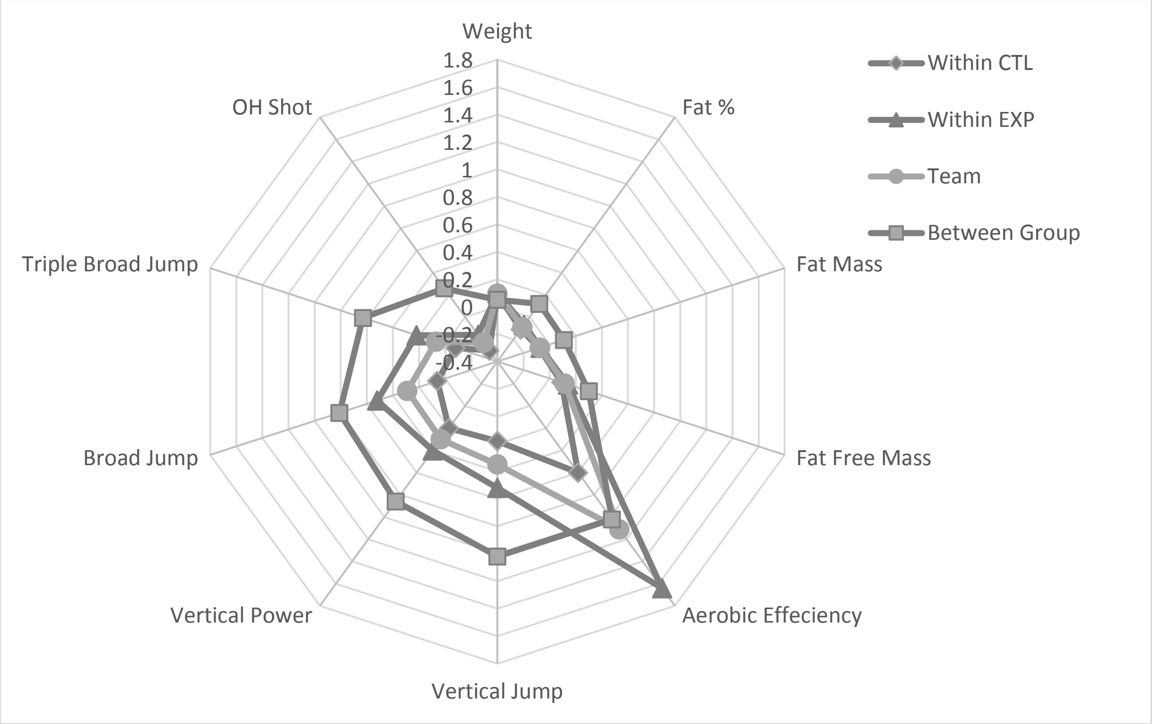
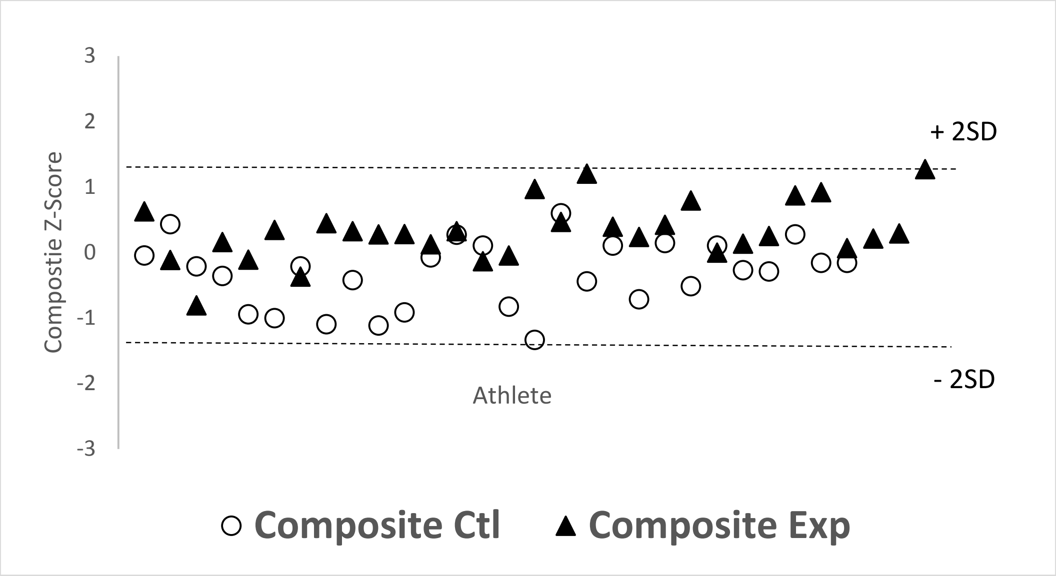


Figure 5 displays the modified Bland-Altman plot of the composite z-scores of all performance outcomes. A fairly clear dichotomy is present between the groups in regards to overall performance. Athletes within the treatment group rank predominantly above population mean compared to athletes in the control group.

Figure 5. Modified Bland-Altman plot representing the composite z-scores for performance outcomes for individual subjects in experimental and control groups.



Discussion

The primary aim of this study was to examine the effect of fluid periodization on performance and anthropometric outcomes in Division-1 collegiate American football players. The treatment group (FP) received daily adjustments based upon Omegawave's assessment of the functional state, while the control group trained according to the prescribed workout without deviation. Significant improvements were found in the treatment group for vertical jump, vertical power, broad jump, and aerobic efficiency. These performance outcomes occurred with a concurrent reduction in resistance training volume ($p < .01$). There were no significant differences found between groups for anthropometric measures, running volumes, triple broad jump, or overhead throw. To our knowledge this study is the first of its kind to use physiological feedback to assess the functional state of strength and power athletes and to make subsequent changes to the daily prescribed exercise volumes and intensities.

Very few studies have examined the effect of daily training adjustments based on physiological feedback. To date most studies have only been able to utilize biochemical markers such as cortisol and testosterone but the use of these markers are often associated with overtraining in which longitudinal outcomes were evaluated (115) (162). The studies that have attempted to modulate daily training loads based on objective physiological feedback have utilized endurance athletes and HRV measurements. For instance, Kiviniemi et al., examined the effect of HRV guided training on 26 moderately fit males and evaluated changes in VO_{2peak} and training loads between groups (89). Although no significant differences were noted in VO_{2peak} between groups, there were significant differences between training volume and maximal running performance, suggesting that HRV guided training may facilitate enhanced performance outcomes at a reduced volume of work. Taken collectively, the findings from Kiviniemi et al. and the present study imply that the timing of the training stimulus and ability to adapt to the stimulus may be more relevant than the volume and intensity prescribed on a given day. Additional studies by the same laboratory have yielded similar results in recreationally trained men and women (88).

To compare the results of the present study to similar periodization studies is unwarranted due to the flexible assignment of daily volumes and intensities. Regardless of the periodization modality, athletes typically adhere to the prescribed training irrespective of their physiological state. Although there is no literature to support fluid periodization as presented in this study, with the use of an AMS, there have been studies that have examined the functional state by either subjective analysis of wellness or some objective measure of performance. The key to these studies and even the present study is that an auto-regulatory element exists in which training is altered based upon some physiological or psychological assessment of the athlete.

Flexible non-linear periodization has been introduced to the strength and conditioning community within the last decade. Daily training alterations are calculated by an individual athlete’s readiness score determined by his or her performance on a standardized test such as a counter movement jump, medicine ball throw, etc. A decrease in the performance score relative to the athlete’s average would warrant a reduction in training volume and/or intensity for that day. This is similar in concept to the present study (i.e., fluid periodization), as training adjustments were made following standard physiological measurements of HRV and DC potential. Limited research is available regarding FNLP, however the few studies that have utilized it have shown promising results. For example, Silvestre et al. used subjective evaluations and heart rate fluctuations during soccer practice and games to assign the volumes and intensities of resistance training sessions (154). Heart rate monitors were worn every practice throughout the season and an exertion score was calculated by Polar Precision Performance Software. If the calculated exertion points for an individual athlete fell one standard deviation above the team average then the athlete would be monitored for signs of overtraining and be given several regeneration days with a reduced work volume. Additionally, weight training volumes were reduced based upon a subjective analysis of the athlete in combination with the weekly exertion scores. The use of FNLP maintained values of vertical jump, short term sprint ability, and maximal oxygen consumption during the course of the season and significantly improved total lean tissue and total body power from pre-season to post-season. This study did not compare FNLP to another type of training, however the results indicated that its use maintained or improved fitness markers throughout the duration of a soccer season, contrary to many studies which indicate performance decrements as the season progresses (96).

The significance of Silvestre et al.'s (154) work is that volume and intensity of loads were altered based upon an objective measure of cardiac stress, as measured by the Polar Precision Performance Software. As mentioned in the literature the evaluation of the cardiac system, whether it's through HRV analysis, changes in resting heart rate, or cardiac exertion can be thought of as the status of the athlete's fuel tank for adaptation. Typically athletes who are under distress from physical or mental factors will often present sympathetic autonomic tone, or elevated heart rates during exercise above the normal response (70). These increased cardiac workloads will increase the impact of the alarm stage and further increase recovery times (81). In team sport environments such as soccer and American football, athletes are exposed to training stimuli on the prescribed day regardless if recovery has fully realized from the previous training session which could progressively lead towards states of exhaustion and mal-adaption. Although the present study did not compare the same outcome variables to those of Silvestre et al. (154) it is important to notice that adaptation to workloads were likely maintained or improved by controlling the volumes and intensities of workloads by utilizing objective physiological feedback.

Similarly, McNamara et al. observed FNLP to be beneficial in developing strength over a standard Non-linear Periodized (NLP) program (119). The NLP undulated between 20, 15, and 10 repetitions, whereas the FNLP was able to choose which workout they wanted to perform based upon a subjective feeling of fatigue. The authors explained the phenomena on the auto-regulation of “mental readiness” in which subjects subjectively rated their fatigue level and matched the workout intensity and volume accordingly. The FNLP group significantly improved leg press strength compared to the NLP group (62 vs. 16 kg). The researchers did not find significant differences in chest press or standing long jump, however a favorable trend was noted in standing long jump ($p = 0.08$). This was most likely due to the increased leg press strength. Although this study was performed on beginning weight trainers in an introductory weightlifting class, it could illustrate the importance of using subjective or objective measures for monitoring overtraining states in athletes with a lesser training age. This may have significant impacts on freshman athletes who have higher incidence of injury occurrence compared to those with greater training age and physical fitness (80).

An alternative form of NLP periodization was developed by Mann et al. in which daily adjustments to the final working set were made based upon the athlete's performance in the previous set of work (112). Essentially a new 1 RM was established on a daily basis, regardless if that was above or below the previous best. The resarchers coined this protocol as Autoregulatory Progressive Resistance Training (ARPE). Mann et al. drew inspiration for the APRE protocol from Delorme who developed a method known as Progressive Resistance Exercise (PRE) (40) and from Knight et al. who adapted the PRE program for rehabilitation of the quadriceps following knee surgery and coined the protocol Daily Autoregulated Progressive Resistance Exercise (DAPRE) (90). This method used PRE to determine the resistance established for the first 2 working sets while a third set was used to determine the load for fourth set. Similar to APRE, the fourth working set served to be flexible in nature depending on the performance on the third set.

Although limited research is available, it has been shown ARPE produces significant strength differences when compared to linear periodization. Mann et al. observed 9.3% and 19.3% improvements in 1RM bench press and squat strength, respectively, when using ARPE compared to 0.4% and 3.7% improvements observed in LP groups (112). These significant differences suggest that auto-regulation based on performance measures may be indicative of an athlete's current functional state and reductions in volumes may reduce injury rates and allow supercompensation to fully develop.

All of the studies mentioned above provide a unique version of fluid periodization in the sense that they use subjective feelings of wellness or objective measures of performance to reflect the individual's training status on a given day. The literature is sparse in regards to physiologically-based fluid NLP, which makes it difficult to draw definitive conclusions regarding the use of subjective or objective feedback to assign daily training loads. However, the results from McNamara et. al. and Mann et al. parallel those observed in the present study regardless of the differing training outcomes (112, 119). The premise of periodization is based on the assumption that the rate of compensation and supercompensation is universal among athletes, however it has been established that genetic differences account for up to 50% of performance variance (68), thus the rate at which supercompensation occurs can vary significantly between athlete subject pools. Additionally, it has been shown that environmental stressors such as lack of sleep, academic stress, social stress, etc. will significantly affect performance outcomes (111, 147). Fluid periodization and auto-regulatory progressive resistance exercise may provide the necessary insight to account for genetic variance and environmental stressors.

The mechanisms of fluid periodization, ARPE, and variants of the two are not completely understood. Mann et al. postulates that greater strength gains are a product of the constant adjustment of repetitions. This approach is very similar to undulating periodization which has shown to be effective in improving strength when compared to linear periodization (140), however a host of studies have demonstrated no difference or contradicting evidence to support the effectiveness of undulating periodization over LP (121) (134) (155). The inconsistency in literature leads many professionals torn between choosing a specific protocol when programming. The discrepancy in research has been attributed to inconsistencies in methodology, sample size, or elite vs. recreational athletes. (139). However, is it possible that we have strayed too far from the foundations of which periodization was established? Supercompensation is the theory that drives the majority of strength and conditioning principles, yet its biggest assumption is that the rate in which supercomensation occurs is fairly uniform among subjects. It is possible that conflicting research is reflective of the variation in subject pool, specifically the genetic make-up and environmental stressors present at the time of the study. The protocol employed in the present study accounts for the stress on the athlete and indicates their readiness to train, or maybe more specific to this study, their readiness to adapt.

With limited research available for the use of the technology utilized in the present study or the use of its concepts, HRV and DC potential, across a broad range of populations, leaves little to postulate a mechanism for its success. However, numerous studies have been employed to quantify stress in athletic populations and observe its effect on performance (16) (13). Additionally, interventions have been imposed to reduce stress in athletic populations which has shown promising results in sport adaptation, sport performance, and overall wellbeing (138) (19). The fundamental basis of periodization is rooted within Selye’s general adaptation syndrome, thus it may be relevant to discuss the interventions that quantify stress, specific and non-specific, and its relationship to athletic performance.

With the exception of HRV guided training in endurance athletes mentioned earlier, the present study is the first to objectively measure stress via HRV and DC potentials and reduce training loads to match the level of adaptability in power athletes.

Although mechanisms are unclear, the success of fluid periodization could be attributed to effective non-specific stress management, allowing athletes to maintain proper balance of the stress-recovery continuum. The importance of the work-to-rest ratio has led researchers to develop methods for monitoring this relationship in the form of subjective questionnaires, immunological responses, and in the case of the present study, HRV (13, 16) (9).

Kellmann and Kallus developed the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) to identify the magnitude to which athletes are mentally and or physically stressed and their perception of recovery (85). Many studies have employed the use of the RESTQ in a variety of athletic populations (82) (37). Jurimae et al. (81) studied the effect of increasing training loads on markers of psychological and physical stress in competitive rowers (82). Significant relationships were observed between training volume and fatigue scores (r=0.49), sleep quality (r=0.58), and somatic complaints (r=0.50). Additionally, relationships were observed between cortisol and fatigue (r=0.48). These relationships are often paralleled with over-reaching and overtraining states, which have been shown to produce stale or under-performance results in athletes (123) .

Additionally, strong relationships between cortisol and decreased HRV have been reported in overreached and overtrained subjects (62) which validates the use of HRV in the present study. Decrements in physical performance were often observed in subjects who reported increased feelings of fatigue, energy, and general stress and were associated with the accumulation of creatine kinase, cortisol, and catecholamine levels. Training without proper monitoring techniques could explain why the control group significantly underperformed compared to the experimental group as testing sessions occurred following an intensive 8 week training program. Although the RESTQ has been shown to be effective in monitoring the training process, its biggest limitation is the low frequency in which it can be administered due to the complexity and time demands of completing the questionnaire. Compared to the present study, athletes are examined daily versus monthly as seen in many psychometric questionnaire studies. The time lag between assessments could be detrimental to those who are experiencing an imbalance of the stress-recovery ratio and stress may go unabated during the 4 week duration between assessments.

At the heart of all the studies presented thus far, a central theme of monitoring an individual's response to training and an evaluation of stress on the athlete is evident. Although we cannot definitively outline the mechanisms of the successful outcomes produced, we can speculate based upon the fundamentals of which training theory exists. Many will argue that Selye's work is not relevant to normal training stimuli, however his work illustrates that every organism has a certain threshold for adaptation or resistance to work loads and once that threshold has been violated then decompensation or overtraining can occur. From Selye's work we can assume that every organism has a certain level of adaptation energy or reserves and that adaptation to non-specific stress will occur as long as resources are available. His work laid the foundation for the works of McEwen to expand on his idea of the general adaption syndrome.

The concept of allostasis and allostatic load is more relevant to athletes compared to Selye and general adaptation. Allostatic load accounts for all factors of environmental stress, specifically mental stress which is often present when working with student athletes. On any given day a student athlete's allostatic load can vary depending on several factors such as exams, homework, relationship tension, or social media pressure. Thus, if an athlete has experienced a significant allostatic load prior to a training stimulus, their resources for adaption may be significantly reduced depending on the magnitude of the incurred stress. Our study examined athletes' HRV at rest which can indicate if they are currently under allostatic load, through increased sympathetic input, or if they are still in a state of allostasis, typically represented by increased parasympathetic input. By altering their training volumes and intensities it is possible that we matched their external load (resistance training) with their internal load as measured by HRV. Therefore the level of adaptation resources was maintained daily which could explain why the treatment group experienced higher training outcomes.

The cardiovascular system is very indicative of the levels of adaptability by giving an indirect measure of adaptation reserves. Having the resources available for adaptation are extremely important for longitudinal success and is represented not only in the present study but by all the studies mentioned thus far. The present study is novel because of its use of HRV in power athletes and the use of the DC potential to measure the level of wakefulness or activity of all functional systems. Since functional systems govern all adaptive processes in the body, athletes training in a reduced functional state will have limited or slowed adaptability regardless of resources available.   The use of the DC potential is sparse in literature and is mainly accepted in Eastern literature, however it is surprising that the majority of research in Western culture has failed to examine the central components' role in the adaptation process. The human organism is dynamic and should not be examined in a reductionist manner, however it should be viewed as a holistic integrated unit. The DC potential is the first method in which the integrative activity of the organism can be evaluated. The use of it in this study may have played a significant role in the success of the treatment group.

The present study implies that the use of HRV and DC potential are effective methods for monitoring stress levels in athletes. This was evidenced by the significant differences observed in vertical jump, vertical power, broad jump, and aerobic efficiency between experimental groups. It was surprising to observe little to no improvements in anthropometric measures, especially in regard to fat-free mass and relative body fat. Although a small effect size was observed in fat-free mass in the treatment group, we would have suspected a larger effect given the significant increases in power outcomes and cardiovascular adaptation. This could be due to the measurement error associated with our measure of body composition (i.e., BodPod). Additionally, the main adaptions pursued were power and power/speed endurance which are also associated with neurological adaptations, not exclusively muscle hypertrophy (146).

Improvements in power production from the present study were less than values reported in the literature. Typical improvements in vertical jump power range from 8-12% (2) (108) compared to the 6% improvement in the treatment group in this study. However, these studies did not have concurrent training modalities seeking to secure multiple training adaptions (i.e., power and aerobic endurance). The cited studies were conducted during a strength or power specific training period, whereas our study examined power outcomes after an intensive aerobic training period (during the 2nd training block). Ideally, power outcomes would have been measured following block one to fully realize the effect of the power/strength training block. However, due to the limited time afforded in a pre-season training regime, performance testing could only be performed following a taper period prior to summer camp training. This limitation should be expected when dealing with elite athletic population in which research becomes secondary to the training process.

There are several limitations to the present study. First, this study was composed of a convenience sample. Ideally subjects would have been randomly assigned without consideration of playing status or year. However, as this research was conducted in an elite population, players who were identified as starters were most likely to participate in the treatment group. One could argue that starters possess better genetic potential which could explain the significant differences observed between the training groups, however physical ability has shown little correlation to on-field success as indicated by several NFL draft studies (102). Skill ultimately becomes the most important factor for determining starters. It should also be noted that no significant differences in anthropometric or performance outcomes were observed between experimental groups in baseline measures so in essence each subject served as his own control as the averages of improvements were taken between groups.

The use of the custom tempo test, rather than a validated aerobic efficiency test such as the intermittent yo-yo, may present some error in the study’s conclusions regarding aerobic conditioning. However, the results from the aerobic efficiency test were fairly robust when comparing experimental groups and in terms of adaptation it may be assumed that adaptation was significantly higher in the treatment group. As mentioned previously, working with elite populations will undoubtedly be met with limitations. Conducting research in this population must not be obtrusive and must be secondary to the training process. Regardless, the results from this population are much more relevant compared to studies examining recreationally trained men. Considering genetics produces a large amount of variability, it is hard to compare the results of studies of recreationally trained populations to those who compete at the highest level.

CHAPTER V

SUMMARY AND CONCLUSION

In summary, the purpose of this study was to determine the effect of fluid periodization training models on athletic performance outcomes with the guidance of an AMS. The results from this study confirmed our hypothesis that the use of objective physiological measures, provided by the AMS, produced significantly higher performance outcomes in vertical jump, vertical power, broad jump, and aerobic efficiency. Additionally, the results confirmed our second hypothesis that these performance outcomes were gained at a reduced physiological cost by significant reductions in both core and accessory resistance training volume.

This is the first study, to our knowledge, that has utilized HRV and DC potentials of brain waves to evaluate the functional state of power athletes and to alter their training volumes and intensities based upon that physiological assessment. This method was successful in securing significantly higher adaptations specific to vertical jump, vertical power, broad jump, and aerobic efficiency in the treatment group compared to the control group. Although precise mechanisms are difficult to identify at this time, the methods used to monitor the athletes' functional state are based upon recognized physiological measurements, are grounded in foundations of training theory and adaptation, and should be considered as a highly effective method for monitoring the training process.

The use of an AMS must be considered when training elite level athletes, especially at the collegiate level where academic stress may play a significant role in stress and recovery. The internal or allostatic loads of an individual can vary significantly from day to day depending on their specific response to environmental stressors. As strength and conditioning professionals we cannot assume that athletes are adapting according to the periodized plan. An objective measure of the physiological state must be employed to ensure that states of overtraining do not occur.

In conclusion, with the conflicting evidence regarding the efficacy of differing modalities of periodized training, it may be assumed that a given training volume and intensity should be assigned to a group of athletes. However, each individual is their own genetic anomaly which responds and adapts to environmental stressors in a unique and unpredictable manner. Fluid periodization is meant to account for said environmental factors and allows internal and external loads to accommodate each other, thus ensuring optimal adaptation. The present study highlights that volume and intensity may not be the ultimate factor when designing periodized programs, yet signifies that the importance of the timing in which the appropriate training stimulus is applied.

Appendix A

Descriptive Statistics (Mean ± SD) of Omegawave Readiness Parameters.

	Stress index	Fatigue	Adaptation reserves	CNS
Week 1	5.15 ± 0.31	5.77 ± 0.32	4.71 ± 0.17	5.32 ± 0.41
Week 2	5.45 ± 0.20	5.89 ± 0.12	4.83 ± 0.07	5.50 ± 0.17
Week 3	5.29 ± 0.19	5.87 ± 0.14	4.77 ± 0.12	6.07 ± 0.07
Week 4	5.22 ± 0.17	5.81 ± 0.31	4.72 ± 0.27	6.08 ± 0.30
Week 5	5.33 ± 0.16	5.74 ± 0.07	4.61 ± 0.10	5.84 ± 0.15
Week 6	5.39 ± 0.26	5.80 ± 0.10	4.69 ± 0.14	5.91 ± 0.23
Week 7	5.52 ± 0.33	5.90 ± 0.23	4.78 ± 0.26	5.72 ± 0.30
Week 8	5.34 ± 0.10	5.85 ± 0.21	4.78 ± 0.20	5.84 ± 0.06

* Arbitrary scale of 1-7 with 1 being the lowest score and 7 being the highest score.

Descriptive Statistics (Mean ± SD) of Russian Heart Rate Variability Parameter’s

	Activity of vagus regulatory mechanisms	Activity of sympathetic regulatory mechanisms	Tension index	Share of the aperiodic influences	Standard deviation of the aspirate waves
Week 1	0.2847 ± 0.0197	34.42 ± 2.1069	105.35 ± 11.54	0.0379 ± 0.0054	1.8542 ± 0.1742
Week 2	0.3277 ± 0.0205	31.44 ± 2.4727	78.12 ± 17.94	0.0421 ± 0.0033	1.8341 ± 0.1375
Week 3	0.3041 ± 0.0131	33.60 ± 1.1868	91.18 ± 11.77	0.0359 ± 0.0023	1.8559 ± 0.1237
Week 4	0.2983 ± 0.0192	34.30 ± 1.6370	100.09 ± 13.07	0.0355 ± 0.0021	1.7425 ± 0.0651
Week 5	0.3169 ± 0.0293	32.53 ± 2.5110	86.87 ± 14.50	0.0368 ± 0.0039	1.7893 ± 0.0959
Week 6	0.3211 ± 0.0265	32.12 ± 2.2217	84.26 ± 17.24	0.0351 ± 0.0024	1.8074 ± 0.1229
Week 7	0.3339 ± 0.0240	29.79 ± 3.5519	70.75 ± 20.14	0.0392 ± 0.0082	1.9209 ± 0.1927
Week 8	0.3031 ± 0.0228	32.61 ± 3.1708	84.11 ± 12.45	0.0371 ± 0.0027	1.8195 ± 0.0523

Descriptive Statistics (Mean ± SD) of Time-Domain Heart Rate Variability Parameters.

	SNNN			SDSD			RMSSD		
Week 1	76.52	±	6.28	92.63	±	9.90	73.60	±	8.06
Week 2	88.57	±	4.53	103.00	±	4.60	82.22	±	3.63
Week 3	81.18	±	4.12	98.35	±	6.98	78.14	±	5.43
Week 4	80.42	±	4.27	99.06	±	9.15	78.63	±	6.86
Week 5	83.97	±	6.19	99.44	±	12.64	78.96	±	9.44
Week 6	83.00	±	5.95	96.26	±	8.98	76.66	±	6.81
Week 7	93.53	±	13.48	105.70	±	17.71	83.78	±	13.93
Week 8	85.74	±	13.49	103.21	±	15.17	82.21	±	12.25

Descriptive Statistics (Mean ± SD) of Frequency-Domain Heart Rate Variability Parameters.

	Total Power			LF/HF			HF			HF n.u.			LF			LF n.u.		
Week 1	2421.42	±	422.68	1.97	±	0.33	1097.79	±	284.59	48.69	±	2.16	1175.99	±	216.50	50.86	±	2.48
Week 2	3144.52	±	527.79	1.88	±	0.25	1250.18	±	157.77	46.15	±	1.71	1599.79	±	345.02	54.37	±	1.75
Week 3	2514.18	±	289.43	1.69	±	0.24	1135.81	±	199.31	48.93	±	1.28	1162.41	±	129.61	51.07	±	0.26
Week 4	2741.37	±	362.98	1.78	±	0.21	1327.69	±	199.85	47.59	±	2.46	1181.46	±	156.11	52.41	±	2.97
Week 5	2610.66	±	422.58	2.16	±	0.65	1161.02	±	325.87	47.89	±	4.28	1189.22	±	142.45	52.11	±	4.28
Week 6	2416.92	±	233.50	2.21	±	0.84	1056.28	±	162.62	47.36	±	5.28	1112.78	±	185.16	52.64	±	5.28
Week 7	3052.23	±	458.97	1.94	±	0.50	1432.28	±	532.80	48.70	±	6.32	1296.86	±	122.22	51.30	±	6.32
Week 8	2746.11	±	949.33	1.80	±	0.27	1311.19	±	428.36	48.53	±	1.26	1207.13	±	680.56	51.47	±	1.26

Descriptive Statistics (Mean ± SD) of Omega Resting Potential

	Omega Resting Potential		
Week 1	11.43382	±	1.535657025
Week 2	10.98248	±	0.660490368
Week 3	16.49275	±	0.615475161
Week 4	17.63882	±	3.546550673
Week 5	14.1203	±	1.005535648
Week 6	15.78333	±	2.156514254
Week 7	14.29096	±	2.36064498
Week 8	14.52664	±	0.820185874

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