8-2021

Implementing of Phase Potentiation Program with College Triathletes

David Fish
East Tennessee State University

Implementing of Phase Potentiation Program with College Triathletes

---

A thesis

presented to

the faculty of the Department of Sport, Exercise, Recreation, and Kinesiology

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Master of Science in Sport Science and Coach Education

---

by

David John Fish

August 2021

Michael Ramsey, Ph.D., Chair

Kevin Carroll, Ph.D., Committee Member

Margaret Stone, M.S., Committee Member

Keywords: phase potentiation, triathlon, resistance training, concentrated load

ABSTRACT

Implementing of Phase Potentiation Program with College Triathletes

by

David John Fish

The purpose of this study is to determine the effectiveness of an in-season resistance training program on improving measures of strength in female collegiate triathletes. Nine females (age = 19.2 ± 1.1 years, height = 166.5 ± 12.5 cm, body mass = 61.1 ± 9 kg) with limited resistance training experience were examined for this study. Formal RT intervention was monitored for 7 weeks with the athletes being assigned 6 weeks of independent RT prior to the pre-test. Athletes completed a standardized athlete monitoring program pre and post resistance training intervention. Paired sample *t*-tests were used to determine differences between conditions with Cohen's *d* effect sizes describing the magnitude of change between pre and post-intervention. No significant changes were found between the two testing sessions ($p > 0.05$). A longer duration of utilizing resistance training adhering to a phase potentiated approach may be necessary for significant changes to occur.

ACKNOWLEDGEMENTS

The author would like to acknowledge and thank all the athletes he got to collaborate with during the training and data collection process. As well, thanks to all who aided in the collection of data. Furthermore, the author would like to acknowledge all contributing authors for all the guidance and support they provided throughout every stage of this thesis process.
I would also like to express my gratitude to the following people:

Dr. Ramsey, thank you for your guidance through this process, especially your enthusiasm and willingness to step up as my Committee Chair. You have helped me develop my knowledge in the field of Sport Science and become a more proficient conductor of the analysis process.

Dr. Carroll, thank you for always making yourself available to aid in furthering my knowledge of the research process. There were numerous instances where your insight was able to guide my efforts as I continued to learn.

Coach Stone, thank you for always supporting my journey to complete this thesis! There were several obstacles along the way but I knew there was always going to be a high degree of support in my corner coming from you.

Finally, the author would like to express the utmost gratitude to Andrew (Tony) Pustina for laying an excellent foundation on which my knowledge of Sport Science is built. As well, thank you for sharing many tools and insights that furthered my learning while at Carthage College and continues to make me a lifelong learner long after I have left the walls of the TARC.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1. Introduction

Resistance training (RT), when performed concurrently with endurance training, allows for athletes to perform at a higher level when implemented appropriately (Aaguaard et al., 2011; Bazyler et al., 2015; Hoff et al., 2001; Støren et al., 2008). Too short of a RT program's duration (<8 weeks duration) or intensity (<80% 1RM loadings) often show limited improvements in endurance performance (Bastiaans et al., 2001; Bishop et al., 1999; Levin et al., 2009). With adequate intensity (≥85% 1RM) (Aaguaard et al., 2011; Hoff et al., 2001; Støren et al., 2008) and explosive type training (Mikkola et al., 2007a, b; Paavolainen et al., 2003) better results, such as economy of movement and fatigue resistance, can occur in endurance athletes (Beattie et al., 2014; Paavolainen et al., 2003). Benefits attributed to RT include improved economy of movement and the ability to produce higher maximal force (Beattie et al., 2014; Paavolainen et al., 2003). These improvements are due to an alteration in myofibril size and contractile properties, these adaptations increase muscular force production (Tanaka & Swensen., 1998).

When applying a phase potentiated approach to RT, athletes may experience varying loads, intensities, and selected exercises that prepare them for their championship competitions later in the season. Phase potentiation requires the use of summated microcycles, in which the volume and intensity variables of training are manipulated in a coordinated manner leading towards a specific goal (DeWeese et al., 2015a). Summated microcycles can also be termed "blocks", in which are concentrated loads (CL). A CL emphasizes one aspect of fitness while all other aspects are de-emphasized (DeWeese et al., 2015a). These blocks will follow the sequential order with the following order of accumulation, transmutation, and realization (Stone et al., 2007) as their respective emphasizes. Depending on the competitive schedule, the duration and selection of blocks can vary. Now the structure and duration of the blocks set up the accumulation of specific characteristics based on the focus of each mesocycle of RT with the intention of positively impacting performance. Both maximal strength (1RM) and countermovement jump (CMJ) were examined in a study by Taipale et al. (2010). In the study, the group exposed to maximal strength and explosive strength training achieved improvements to their strength and neuromuscular performance. Rate of force development (RFD), another important variable, is attributed to neural adaptations from improvements in strength. This yields improvement to aerobic endurance via enhanced work economy (Hoff et al., 2001).

Variables such as jump height (JH) and rate of force development (RFD) are frequently attributed to RT (Aagaard et al., 2002; Andersen et al., 2010; Byrne et al., 2020; Kraemer et al., 2003; Mangine et al., 2016) and their relationship with aerobic performance has been previously examined (Kons et al., 2018; Lum et al., 2020). RT is a stimulus that can improve mechanical efficiency (Sunde et al., 2010; Yamamoto et al., 2008), muscle coordination, motor unit recruitment patterns (Sale 1988), and lower limb stiffness regulation. These improvements correlated with enhancements in running economy (RE) (Mikkola et al., 2011; Millet et al., 2002) and cycling economy (CE) (Sunde et al., 2010).

Fatigue resistance is important for triathletes since there can be an additive effect of fatigue from the previous discipline (García-Pinilloset et al., 2016; Noakes 2000), this will impact the next segment of the race. Early on, having a high economy of movement will benefit the endurance component of sports like distance running, distance cycling, and triathlon. Having a more economical movement pattern in endurance events means there is less energy being utilized inefficiently. This can be attributed to fewer motor units needing to be recruited at the same time at a given intensity (in addition to maintaining efficient technique of movement). So being more economical in the cycling leg of a triathlon, for example, would set the athlete up for having accumulated less fatigue when progressing on to the running segment. This lengthens the onset of muscle fatigue and increases time to exhaustion at that specific intensity (Sunde et al., 2010).

Currently, there is a lack of research for RT and the impact it has on triathletes. This athletic population must train in 3 distinct disciplines (swim, bike, and run), making the demands of the sport different from swimming, cycling, or running. Where characteristics of cycling and running benefit most from RT, studies that examined RT's impact on these disciplines focused solely on the specific means for training and not the compounding impact swim, bike, and run has on an athlete (Millet et al., 2002; Paavolainen et al., 2003; Støren et al., 2008; Sunde et al., 2010). For one, by the time a triathlete is entering the run portion of a competition, they are already pre-fatigued from the swim and bike, with impairments in RE frequently observed after cycling (Bonacci et al., 2009). As well, triathletes need to dedicate time to each discipline often performing multiple disciplines in one day. The addition of RT may be challenging to incorporate into a triathlete's training due to time constraints over the course of a week or the demands that swimming, cycling, and running have.

Statement of Problem

Phase potentiation has been previously investigated but there is a need for a full description of the effects of this programming tactic with endurance athletes (Harris et al., 2000; Minetti et al., 2002; Zamparo et al., 2002). Bazyler et al. (2015) stated that "phase potentiation, is essential in the development of endurance-specific performance characteristics." Being able to effectively incorporate this training approach is needed alongside sport-specific training for triathletes.

Utilizing a phase potentiated approach to RT is commonly implemented in many sports. To the authors' knowledge, there are no previous studies that examine this method of conditioning with triathletes. The purpose of this study is to determine the effectiveness of an in-season RT program on improving measures of strength in female collegiate triathletes. This is to examine the changes in JH, peak force, and RFD when the volume and intensity variables of a RT program have been manipulated throughout multiple blocks/phases. The expected outcome is that the variables of JH and RFD will improve from pretesting to post-testing.

Chapter 2. Comprehensive Review of Literature

Introduction

The purpose of this literature review is to provide context into how phase potentiation (otherwise known as block periodization) can enhance athlete performance. Through using block periodization, concentrated loads are linked to allow stimuli that are not present in training to be experienced by the athletes (DeWeese et al., 2015a). Concentrated loads produce aftereffects that persist into the next phase, hence "phase potentiation" (DeWeese et al., 2015a; Suchomel et al., 2018). Phase potentiation, when providing heavyweight training over many weeks or a few blocks should be followed by speed-strength training to produce improvements in RFD, speed, and power gains (DeWeese et al., 2015b; Suchomel et al., 2018).

Phase Potentiation

Phase potentiation is a recent enhancement of the concept of periodization. It is important to first define periodization as the "logical, sequential, phasic method of manipulating training variables to increase the potential for achieving specific performance goals while minimizing the potential for overtraining and injury through the incorporation of planned recovery" (DeWeese et al., 2015a). The primary goals of periodization include an appropriate balance of training loads and competitive readiness during the season, fatigue management and the reduction of overtraining potential, and adequately staging and timing of the peak (DeWeese et al., 2015b). For periodization to be effective, variation is needed to manipulate variables and manage fatigue. Variation is needed to meet these goals, which can be achieved through the manipulation of volume, intensity, and exercise selection (DeWeese et al., 2015b). It is with this variation that factors, such as fatigue management, resulting from greater variation and adequate disruption of homeostasis will promote additional adaptation (DeWeese et al., 2015b). To define this process further: “training is recognized as a process which prepares an athlete, technically, tactically, psychologically, physiologically, and physically for the highest possible levels of performance” (Stone et al., 2007). “Training is multi-factorial in nature; as such the attempt is to exploit known principles of physics, physiology, and psychology in order to maximize the effects of the training stimulus. The training process is vitally concerned with the positive enhancement of performance—therefore the process must provide: an appropriate stimulus for adaptation, an appropriate means for assessing progress, and additional means beyond sets and reps including rest–recovery phases, psychological re-enforcement, daily nutrition, supplements, sleep, etc. so that recovery–adaptation is optimized” (DeWeese et al., 2015a).

Traditional Periodization

Before block periodization, traditional periodization theory was the predominant approach to structuring an athlete's training. However, there are limitations to traditional periodization theory: 1) the inability to provide multiple peak performances over many competitions; 2) drawbacks to long-lasting mixed training programs; 3) negative interactions of non-compatible workloads during traditional mixed; 4) insufficient training stimulus for progressing certain abilities among highly qualified athletes (Issurin, 2008). Additional issues arise from prolonged mixed training which includes: 1) excessive fatigue accumulation (this can be indicated by observing the increase in stress hormones and creatine phosphokinase), 2) remarkable results initially but stagnation or reduced improvement rate later on, and 3) intensive exhaustive training lasting 3-4 weeks causes a pronounced stress response leading to an increased risk of overtraining (Issurin, 2008). As well, mixed training elicits conflicting responses when loads of certain training modalities suppress or eliminate the effect of work-loads directed at other targets (Issurin, 2008).

Components of Block Periodization

It is important to break down block periodization into the components that establish its structure. This begins with macrocycles which Issurin (2008) states: “are divided into training periods that fulfill a key function in traditional theory as they divide the macrocycle into two major parts: the first for more generalized and preliminary work (preparatory period); the second for more event-specific work and competitions (competition period). In addition, a third and shortest period is set aside for active recovery and rehabilitation". Macrocycles can then be broken down into mesocycles which focus on achieving morphological, organic, and biochemical changes. To achieve morphological, organic, and biochemical changes from training, this requires lasting at least 2-6 weeks, which correspond to the duration of mesocycles; hence, training blocks are mostly mesocycle-blocks (Issurin, 2008). Three types of mesocycle-blocks were established: 1) accumulation, which was intended to develop basic abilities such as aerobic endurance, muscle strength, and general technical ability; 2) transformation, which was devoted to enhancing event-specific motor and technical abilities, e.g. aerobic-anaerobic or anaerobic endurance, muscle endurance, and proper technique; and 3) realization, which focused on pre-competitive preparation, e.g. race simulation, maximal speed improvement, and recovery after preceding exhaustive workloads (Issurin, 2008). These mesocycles typically determine the total number of training stages in an annual cycle usually. This will vary depending on the features of each sport, the calendar, and the frequency of important events but ranges from four to seven mesocycles (Issurin, 2008).

Mesocylcles can be broken down into a microcycle which is the shortest repeatable cycle and is typically specified as 1 week (DeWeese et al., 2015b). Often 4 ±2 microcycles will make up a mesocycle, as this timeframe has been observed to be optimal for summating cumulative after-effects from training while being short enough to ensure that stagnation from poor variability does not occur (DeWeese et al., 2015b). Typical volume or intensity will increase for 3 weeks followed by an “unload” week over the course of a block. It should be noted that the volume or intensity may increase ranging from 2-6 weeks at times (Plisk & Stone, 2003). The purpose of an unload week is to create variation in workload so that the possibility of overtraining is reduced or to set the table for supercompensation to take place. Supercompensation is an over-shoot in the level of a specific variable past the initial baseline (DeWeese et al., 2015b). Planning an overreaching or functional overreaching is one means by which supercompensation can be effectively utilized. DeWeese et al. (2015b) states that “planned over reaching is an intentional, substantial, sudden increase in volume or intensity that places the athlete in a state of functional over-reaching. Functional overreaching occurs provided the overreaching (increased volume/intensity) phase is not too extensive or long lasting. Thus, for RT, over-reaching can occur as a result of a large increase in volume-load (VL) (or other conditioning activities depending upon the event/sport)”. However, there is a possibility that overreaching can result in chronic fatigue and other symptoms similar to the initial stages of overtraining (i.e. drop in performance, sleeping problems, headaches, decreased immunity, and depression to name a few). As long as the overreaching phase is not too extensive, returning to normal training volumes can result in a super compensatory effect, promoting an increased performance. Performance improvements can be associated with alterations in the anabolic state which may be coupled with changes in the testosterone:cortisol (T/C) ratio (DeWeese et al., 2015b). This requires appropriate planning of the overreaching phase to take place followed by the return to normal training. Performance may be enhanced following an overreaching phase and be an effective tool to utilize before an exponential taper.

Appropriate variation aids in the reduction of non-functional over-reaching as well as the potential for overtraining and management for general fatigue. When working with advanced level athletes, relatively heavy and intense training loads are needed to promote adaptation but "constant or very frequent heavy loading can markedly increase "training strain" which can augment the potential for poor or even negative training outcomes, including increased injury" (DeWeese et al., 2015b). Multiple "light" days within a microcycle are needed for recovery to occur from the implemented stimulus. This allows a given training load to be accomplished with a greater potential for positive adaptations and fewer negative outcomes (DeWeese et al., 2015b). DeWeese et al., (2015b) states: appropriate variation in volume and intensity can offset fatigue-induced alterations in 1RM. Variation within the microcycle can efficiently be produced by using a heavy/light day system. Appropriate variations in volume and intensity of training are essential to promote adequate recovery from intense training sessions and reduce the chance of accumulated fatigue and overtraining. Additionally, the heavy and light days ensure that a variety of power outputs will be used, potentially resulting in beneficial alterations to the power–load spectrum.

Relative Intensity

Another variable that should be manipulated is relative intensity (RI), which is often represented as a percentage range based on an individual's 1 RM. RI should vary for two primary reasons: fatigue management and to present the athlete with a broad spectrum power–load curve (DeWeese et al., 2015b). Intensity should be made so it fits the needs of the characteristics, the type of exercise, the set/repetitions scheme, and the fatigue level. The range of RI can reduce the likelihood of potential problems, especially as it concerns accumulative fatigue (DeWeese et al., 2015b). Maximum efforts should be made to maximize adaptations, that is, there needs to be intent while moving the weights during the concentric phase. This means concisely performing the movement with an appropriate velocity of movement. To clarify DeWeese et al. (2015b) states: "the calculation of an RI based on a specific set and repetition configurations should be used instead of relying on a 1 RM. In this manner, the RI may be conceptualized as more of a function of the work to be accomplished (a summation of sets and reps) rather than repetitions as a function of the 1 RM. However, in creating successful microcycle variation, the effects of other training activities must also be considered".

Concentrated Loads

There are other important considerations to have while implementing RT following a block periodization format. First, highly concentrated training workloads cannot be managed at the same time for multiple targets and therefore, the number of abilities being developed simultaneously should be radically reduced (DeWeese et al., 2015a; Issurin, 2008). This means specific characteristics need to be focused on in each block. This can include returning from the off-season, improving work capacity, developing max strength, and focusing on the velocity of movements specific to the sport. It should be noted that the block training method is more efficient for improving maximal strength and RFD development when compared to traditional periodization. Støren et al., (2008) reported after an 8-wk maximal strength training intervention, significant improvements in 1RM half-squat (33.2%), RFD half-squat (26.0%). Concentrated loads are coordinated appropriately at the right time to produce desired results. As well, “planned functional overreaching” should be utilized alongside concentrated loads to promote additional adaptation while taking advantage of the fitness–fatigue paradigm. This combination may positively affect future training through phase potentiation, as a result of the accumulation of residual effects (DeWeese et al., 2015a). Block periodization links a sequence of concentrated loads. A concentrated load is unidirectional and this indicates that that one characteristic of physiological development (e.g., endurance, strength, or power) is being emphasized at that point in training. This does not mean that training is exclusive to that characteristic, but rather that a particular fitness characteristic is being emphasized and other aspects of training de-emphasized through the implementation of retaining loads (minimal doses to maintain specific fitness characteristics). Concentrated loads produce after-effects or residual effects that persist into the next phase. In other words, these after-effects potentiate the next concentrated load" (DeWeese et al., 2015b). Specifically, the block group demonstrated significantly greater increases in the 1repitition squat, and isometric values when differences in volume load were considered. (Painter et al., 2012). As well, to attain morphological, organic, and biochemical changes, periods of at least 2-6 weeks, which correspond to the duration of mesocycles are necessary to promote the focus adaptations adequately; hence, training blocks are mostly mesocycle blocks (Issurin, 2008). These blocks consist of three specialized types: 1) developmental, where workloads attain maximal level; 2) competitive, which focuses on competitive performance; and 3) restoration, which is intended to provide active recovery and prepare athletes for the next developmental program (Issurin, 2008). To implement the block model effectively, several levels of variation, including the use of heavy and light days of training in which the amount of work performed (volume load) is reduced for the light day as needed. This type of loading paradigm has the potential to enhance recovery and adaptation processes, leading to superior performance (Painter et al., 2012).

Taper Implementation

Implementation of a taper block is another method that has the potential to lead to improved performance when programmed correctly. A taper can be described as "a specialized exercise training technique which has been designed to reverse training-induced fatigue without a loss of the training adaptations” (Neary et al., 1992). Tapering involves the manipulation of various factors including training volume, intensity, frequency, and duration (Mujika et al., 2003). Primarily occurring just before the focal or major competition of the season or year, a taper seeks to reduce training load with the goal of experiencing enhanced performance preceding the planned unloading. Specifically, a taper should be able to (when applied correctly) reduce the negative physiological and psychological impact of daily training (i.e., accumulated fatigue), rather than achieve further improvements in the positive consequences of training (i.e., fitness gains) (Mujika & Padilla, 2003). By utilizing what is known as an "intentional overreaching phase" this will, in turn, results in higher performance gains. This is due to utilizing the taper duration and percentage decrease in training load as a means to dissipate this extra accumulated fatigue. The utilization of a taper can be implemented with athletes such as runners (Houmard et al., 1994), swimmers (Mujika et al., 2003), cyclists (Neary et al., 2003), rowers (Jurimae et al., 2003), and triathlon (Margaritis et al., 2003), the effects of tapering have resulted in significant improvements in these disciplines.

In Effects of Tapering on Performance: A Meta-Analysis, it was observed, that improvements from various sports were more sensitive to the reduction in training volume (Bosquet et al., 2007). When inducing a taper to decrease training volume, the goal is to do so by reducing the duration of each training session (Neary et al., 2003) rather than eliminating entire practices. However, some studies prefer to manipulate the training frequency (i.e., the number of training sessions per week) to decrease the weekly training volume (Mujika et al., 1996). When attempting to induce a taper via a reduction in training volume, there should be a decrease in the duration of each training session and/or a decrease in training frequency. It seems that the first strategy should be preferred because decreasing training frequency does not result in a significant performance improvement (Bosquet et al., 2007). It was observed, in highly trained middle-distance runners, that maintaining training frequency (i.e., training daily during a 6-d taper) brought about significant performance gains in an 800-m race, whereas resting every third day of the taper did not (Mujika & Padilla 2003). This method of reducing training load through a decrease in training frequency often interacts with other moderator variables. Items such as training intensity or the form and duration of the taper, which make it difficult to isolate precisely its effect on performance (Bosquet et al., 2007). It should be noted that training load should not be reduced at the expense of training intensity (Bosquet et al., 2007). So for an effective taper to be implemented in the training, it should approach the reduction of the training load by reducing the length of the practices during the week while maintaining a high enough intensity.

Neural Development Attributed to RT

Early increases in muscle strength are a result of neural factors (increased activation, more efficient recruitment, motor unit synchronization, and excitability of alpha-motor neurons or decreases Golgi tendon organ inhibition) in the early phases or hypertrophic adaptations in the long term or a combination of the both (Hickson et al., 1988; Hokka et al., 2014; Millet et al., 2002; Sunde et al., 2010). Paavolainen et al. (2003) concluded that explosive-strength training should also be incorporated since it yields increases in the amount of neural input to the muscles during rapid dynamic and isometric actions. This would imply that "the increase in net excitation of motor neurons could result from increased excitatory input, reduced inhibitory input, or both". Paavolainen et al. (2003) also stated that "neural activation of the trained muscles during explosive-type strength training is very high, the time of this activation during each single muscle action is usually so short that training-induced muscular hypertrophy and maximal strength development take place to a drastically smaller degree than during typical heavy-resistance training". This type of conditioning would be advantageous to sports (endurance running and jumping events) were maintaining weight is preferred over increases in lean body mass. Changes that occur due to RT are initially a result of neuromuscular adaptation when strength is increased (Aagaard et al., 2002). Mikkola et al. (2011) found that 8 weeks of concurrent RT and endurance training improved endurance and selective neuromuscular (3-4%) performance measures. Following neuromuscular changes, improvement in long-term endurance capacity is attributed to an increase in the portion of type IIA muscle fibers (Aagaard et al., 2010) which are less fatigable and able to produce high contractile power (Bottinelli et al., 1999). In addition to heavy-resistance strength training results in neural and muscle hypertrophic adaptations that are known to be primarily responsible for improved strength performance (Mikkola et al., 2011; Paavolainen et al., 2003). This causes improvements in long-term endurance capacity (60-min time trial) in well-trained competitive cyclists as a response to concurrent strength endurance or endurance training long respectively (Bastiaans et al., 2001). This does, however, require appropriate duration and in studies using a short duration (<8 weeks loading) (Bastiaans et al., 2001; Bishop et al., 1999; Levin et al., 2009) was not enough to elicit improved long-term endurance performance. It should be noted that concurrent strength and endurance training can lead to elevated muscle strength even in the absence of muscle fiber hypertrophy (Aagaard et al., 2010; Bishop et al., 1999; Hickson et al., 1988). This method was however contradicted by Hickson et al. (1988) and Bishop et al. (1999) who found that concurrent strength and endurance training may result in elevated maximal muscle hypertrophy.

RFD as it Relates to RT

Changes in RFD (or one's ability to generate force) increased 20% following the period of concurrent strength-endurance training (Aagaard et al., 2010). The maximal RFD has important functional consequences as it determines the force that can be generated in the early phase of muscle contraction (0-200ms) (Aagaard et al., 2002). A 12-20% increase in maximal muscle strength and RFD in response to 16-week concurrent strength endurance program (Aagaard et al., 2010) (add other sources from the article), however, Häkkinen et al., (2003) concluded that over 21 weeks of training, the strength-endurance group showed no significant increases in RFD. Increases in RFD and impulse were observed after heavy-resistance strength training. These findings could be explained by an enhanced neural drive, as evidenced by marked increases in electromyography (EMG) signal amplitude and rate of EMG rise in the early phase of muscle contraction (Aagaard et al., 2002). The increased RFD, while the muscles are under a potentiated condition, is accompanied by a decrease in time to peak force and has been theorized to enhance performance in subsequent athletic activities that use the potentiated muscle groups (Hancock et al., 2015). When maximal strength training is utilized, with an emphasis on neural adaptations, improvements in strength (particularly RFD) and aerobic endurance by improved work economy are also experienced (Hoff et al., 2001). This implies that as RFD improves so will aspects of movement economy that will benefit the endurance component of sports like distance running, distance cycling, and triathlon. Improvements related to economy can be attributed to fewer motor units needing to be recruited at the same time at a given intensity (in addition to maintaining efficient technique of movement). This delays a longer the onset of muscle fatigue and increasing time to exhaustion at that specific intensity (Sunde et al., 2010).

RT and its Impact on Endurance Sports

Traditional endurance training is often the focus for sports such as swimming, cycling, and running. The focus of this training is to perform low-resistance, high-repetition exercises (with repetitions usually being +10). However, this has little impact on strength and anaerobic power since those capacities are not being achieved during training sessions. RT, on the other hand, improves an athlete's ability to perform high-resistance exercises with low repetitions and marginally affects endurance performance (Tanaka & Swensen 1998). Positive muscular adaptations attributed to RT which can lead to improved endurance performance may include increased anaerobic enzyme activity, increased force production, increased intramuscular glycogen, or shifts within major fiber type groups. Neural adaptations may include improved motor unit recruitment and synchronization, improved force development rate, and improvements in the stretch-shortening cycle (Yamamoto et al., 2008). As a result of these distinct muscular adaptations, endurance training facilitates aerobic processes, whereas weight training increases strength and anaerobic power. Some performance data does not fit this paradigm, however, strength training or the addition of strength training to an endurance exercise (running and cycling included) regimen increases short- or long-term work capacity in sedentary or well-trained individuals during treadmill exercise or cycle ergometry. Additional data show that strength training improves the lactate threshold in untrained subjects during cycling. These improvements may be linked to strength training's ability to alter myofiber size and contractile properties, adaptations that may increase muscle force production (Tanaka & Swensen 1998). "Maximal strength training" has been used to describe strength training using high loads, few repetitions, and emphasis on neural adaptations to strength enhancement rather than muscular hypertrophy. Strength training has been associated with reduced endurance performance. But when combining endurance training with maximal strength training, several studies have reported an improved work economy of approximately 5% in various activities such as cross-country skiing, soccer, and running (Sunde et al., 2010).

Concurrent Training

Concurrent training (CT) is widely described in the literature as an effective training method for improving aerobic capacity, muscle strength, and power (Leverittet al., 2003). Paavolainen et al. (1999) utilized explosive strength training in a 9-week study and examined improvements in RE by testing subjects in a 5k time trial. Changes that were found were significant and suggested improvements in neuromuscular characteristics which transferred into improved power of the muscle and economy of movement. Millet et al. (2002) also found improvements to RE from concurrent RT with endurance running after a study that lasted 14 weeks in duration. Kelly et al. (2008) examined the effects CT would have on a group of recreational female endurance runners. There were greater improvements in 3k time trial results following the intervention on CT when compared to the endurance-only group and improvements in upper and lower body strength were present in the concurrent group, but these results were nonsignificant. It should be noted that there were no negative results with the addition of RT to the endurance running program. Taipale et al. (2014) utilized mixed maximal and explosive exercises as the RT intervention concurrently with endurance running below lactate threshold over a 16-week study. CMJ was assessed and improvements were found 8 weeks into the study for male subjects and 12 weeks into the study for female athletes. Taipale et al. (2010) conducted another study on endurance runners where subjects completed a 6 week preparatory RT program before getting divided into maximal strength, explosive strength, and circuit training for 8 weeks. Both maximal strength (1RM) and CMJ in all groups, but the groups exposed to maximal strength and explosive strength training were more impacted by improvements to their strength and neuromuscular performance. Mikkola et al., (2011) conducted a study that followed the same preparatory and specific training duration as Tiapale. Only the heavy RT group has significant improvements in CMJ height (from 28.4 ± 3.5 to 30.1 ± 3.9 cm), all the other groups did have some degree of improvement, however, it was not significant. It should be noted that this study was conducted with RT sessions occurring on different days than the endurance sessions. Aagaard et al., (2011) examined RT and the effects it had on endurance capacity and muscle fiber composition in young top-level cyclists over a 16-week duration. RFD increased by 12-20% following CT in where the group that only performed endurance training had unaffected RFD. Häkkinen et al., (2003) concluded that over 21 weeks of training, the strength-endurance group showed significant increases in RFD. Finally, Glowacki et al., (2004) utilized a CT program with untrained male athletes over a 12-week study. No significant change in JH was present and the CT did not interfere with strength development but it was proposed that there could be a hindrance to the development of maximal aerobic capacity.

RT and its Impact on Swimming

RT, as it relates to swimming, has minimal benefits to enhancing performance (to a certain degree). In swimming, dryland training (conditioning that takes place outside of the water) has shown little evidence of improving performance in this event (Hancock et al., 2015; Tanaka et al., 1993; Tanaka & Swensen, 1998). Due to how technical a swimming stroke is, traditional RT is not specific enough to improve swim performance (Tanaka & Swensen, 1998), however, that doesn't mean there is no improvement to the economy of movement. In shorter distances ranging from 23-400m improvements can be observed in swimmer's velocity that can be attributed to more economical movement (Tanaka & Swensen, 1998). It should be noted that collegiate triathlon and Ironman events will range from 750 meters to 3.9km (2.4 miles), anywhere from double to five times the distance of the maximal side of the range of ideal swimming lengths where performance from RT can be observed.

RT and its Impact on Cycling

Cycling can benefit from RT and increase RFD (benefiting movement economy), which was observed in top-level cyclists (Aagaard et al., 2007, 2010) that could have contributed to a reduced degree of muscle fiber exhaustion for a given cycle power output during long-term endurance (time trial) events. Similarly, 8 weeks of maximal strength training improved CE, work efficiency, and time to exhaustion at maximal aerobic power among competitive road cyclists despite a decrease in total weekly cycle training. There was no concurrent increase in body weight or maximal oxygen uptake (Sunde et al., 2010). This can be explained by strength endurance training enabling cyclists to rapidly produce more pedal force and allow them to maintain a prolonged relaxation phase in each pedal revolution. The improved RFD would allow for a shorter propulsion phase for a given power output (Aagaard & Anderson 2010). It should be noted, however, a lack of improvements in well-trained cycling/triathletes in a 30-km time trial conducted by Levin et al. (2009) after a short-term (9 weeks), low-resistance ("power" type) strength training that was used (Bastiaans et al., 2001).

RT and its Impact on Running

RT as it relates to running benefits in a similar manner to that of cycling. Improved RFD, as well as the economy of movement, was experienced if the duration and intensity of the program were appropriate to cause neural adaptations. Heavy-resistance strength training has improved the endurance performance of previously untrained subjects or RE of female distance runners without changes in VO2max suggesting that neuromuscular characteristics may also be important for endurance performance (Paavolainen et al., 2003). Since faster, larger, and stronger fibers generate more force, weight-trained runners may be able to exercise longer at each submaximal workload by reducing the force contribution from each active myofiber or by using fewer of them (Tanaka & Swensen, 1998). The improvement in submaximal workload due to the force contribution from each active myofiber is how movement economy is enhanced relative to runners. CMJ height increased in a study by Hokka et al. (2014) which examined the strength, power, and endurance characteristics of mixed maximal strength and explosive exercises vs circuit training with bodyweight. Subjects had a background in endurance running. Significant improvements we observed over 16 weeks where the bodyweight group only saw improvements over 12 weeks. Muscle activation, and 1RM in the experimental groups while also improving peak running speed.

Fatigue and Diminishing Effect of RT Program

There are concerns about how fatigue from triathlon training may diminish the effects of a RT program, especially when a RT session immediately follows a sport-specific endurance session (Leveritt et al., 1999; Sparto et al., 1997). Potential causes for poor performance during the RT session can be caused by a poor refueling (hydration and glycogen depletion) after a hard workout has been completed, muscle damage that was accumulated (Abernethy et al., 1999), or the athlete has become mentally fatigued and can no longer perform the prescribed RT program with intent. There should also be appropriate fatigue management during the RT session such as appropriate intensity selection and adequate rest between sets. A hypothesis by Leveritt et al. (1999) proposes that residual fatigue from an endurance session compromises the ability to develop tension during RT. It is proposed that the repeated acute reductions in the quality of strength training sessions then lead to a reduction in strength development over time. This is thought to be attributed to peripheral fatigue factors specific to endurance exercises such as muscle damage and glycogen depletion. Triscott et al. (2008) found that following the exhaustive exercise of a non-exercised bicep of the other arm for resistance athletes and control participants there was a diminished performance, whereas there was no change in the endurance athletes.

There is the consideration of placing the RT session before the sport-specific training session, however, the same problem may arise where the proceeding training session is done in a fatigued state (Doma et al., 2017). So preferably the sport-specific session occurs first so appropriate practices and intents during workouts may take place for desired adaptation and performance outcomes. This is so athletes are "fresh" for a sport-specific workout and they are not entering practice in a pre-fatigued physical or mental state. The primary concern is that the fatigue state induced by a swim/bike/run workout would cause diminished performance or intent while attending a RT session later on that same day.

Chapter 3. Implementing of Phase Potentiation Program with College Triathletes

David Fish, Michael Ramsey, Margaret Stone, Kevin Carroll

Original Investigation

Center of Excellence for Sport Science and Coach Education, Department of Exercise and Sport Sciences, East Tennessee State University, Johnson City, TN, USA

Abstract

The purpose of this study is to determine the effectiveness of an in-season resistance training program on improving measures of strength in female collegiate triathletes. Nine females (age = 19.2 ± 1.1 years, height = 166.5 ± 12.5 cm, body mass = 61.1 ± 9 kg) with limited resistance training experience were examined for this study. Formal RT intervention was monitored for 7 weeks with the athletes being assigned 6 weeks of independent RT prior to the pre-test. Athletes completed a standardized athlete monitoring program pre and post resistance training intervention. Paired sample *t*-tests were used to determine differences between conditions with Cohen's *d* effect sizes describing the magnitude of change between pre and post-intervention. No significant changes were found between the two testing sessions ($p > 0.05$). A longer duration of utilizing resistance training adhering to a phase potentiated approach may be necessary for significant changes to occur.

Keywords: phase potentiation, triathlon, resistance training, concentrated load

Introduction

Resistance training (RT), when performed concurrently with endurance training, allows for athletes to perform at a higher level when implemented appropriately (Aaguaard et al., 2011; Bazyler et al., 2015; Hoff et al., 2001; Støren et al., 2008). Too short of a RT program's duration (<8 weeks duration) or intensity (<80% 1RM loadings) often show limited improvements in endurance performance (Bastiaans et al., 2001; Bishop et al., 1999; Levin et al., 2009). With adequate intensity (≥85% 1RM) (Aaguaard et al., 2011; Hoff et al., 2001; Støren et al., 2008) and explosive type training (Mikkola et al., 2007a, b; Paavolainen et al., 2003) better results, such as economy of movement and fatigue resistance, can occur in endurance athletes (Beattie et al., 2014; Paavolainen et al., 2003). Benefits attributed to RT include improved economy of movement and the ability to produce higher maximal force (Beattie et al., 2014; Paavolainen et al., 2003). These improvements are due to an alteration in myofibril size and contractile properties, these adaptations increase muscular force production (Tanaka & Swensen., 1998).

When applying a phase potentiated approach to RT, athletes may experience varying loads, intensities, and selected exercises that prepare them for their championship competitions later in the season. Phase potentiation requires the use of summated microcycles, in which the volume and intensity variables of training are manipulated in a coordinated manner leading towards a specific goal (DeWeese et al., 2015a). Summated microcycles can also be termed "blocks", in which are concentrated loads (CL). A CL emphasizes one aspect of fitness while all other aspects are de-emphasized (DeWeese et al., 2015a). These blocks will follow the sequential order with the following order of accumulation, transmutation, and realization (Stone et al., 2007) as their respective emphasizes. Depending on the competitive schedule, the duration and selection of blocks can vary. Now the structure and duration of the blocks set up the accumulation of specific characteristics based on the focus of each mesocycle of RT with the intention of positively impacting performance. Both maximal strength (1RM) and countermovement jump (CMJ) were examined in a study by Taipale et al., (2010). In the study, the group exposed to maximal strength and explosive strength training achieved improvements to their strength and neuromuscular performance. Rate of force development (RFD), another important variable, is attributed to neural adaptations from improvements in strength. This yields improvement to aerobic endurance via enhanced work economy (Hoff et al., 2001).

Variables such as jump height (JH) and rate of force development (RFD) are frequently attributed to RT (Aagaard et al., 2002; Andersen et al.,2010; Byrne et al., 2020; Kraemer et al.,2003; Mangine et al., 2016) and their relationship with aerobic performance has been previously examined (Kons et al., 2018; Lum et al., 2020). RT is a stimulus that can improve mechanical efficiency (Sunde et al., 2010; Yamamoto et al., 2008), muscle coordination, motor unit recruitment patterns (Sale 1988), and lower limb stiffness regulation. These improvements correlated with enhancements in running economy (RE) (Mikkola et al., 2011; Millet., et al 2002) and cycling economy (CE) (Sunde et al., 2010).

Fatigue resistance is important for triathletes since there can be an additive effect of fatigue from the previous discipline (García-Pinilloset et al., 2016; Noakes 2000), this will impact the next segment of the race. Early on, having a high economy of movement will benefit the endurance component of sports like distance running, distance cycling, and triathlon. Having a more economical movement pattern in endurance events means there is less energy being utilized inefficiently. This can be attributed to fewer motor units needing to be recruited at the same time at a given intensity (in addition to maintaining efficient technique of movement). So being more economical in the cycling leg of a triathlon, for example, would set the athlete up for having accumulated less fatigue when progressing on to the running segment. This lengthens the onset of muscle fatigue and increases time to exhaustion at that specific intensity (Sunde et al., 2010).

Currently, there is a lack of research for RT and the impact it has on triathletes. This athletic population must train in 3 distinct disciplines (swim, bike, and run), making the demands of the sport different from swimming, cycling, or running. Where characteristics of cycling and running benefit most from RT, studies that examined RT's impact on these disciplines focused solely on the specific means for training and not the compounding impact swim, bike, and run has on an athlete (Millet et al., 2002; Paavolainen et al., 2003; Støren et al., 2008; Sunde et al., 2010). For one, by the time a triathlete is entering the run portion of a competition, they are already pre-fatigued from the swim and bike, with impairments in RE frequently observed after cycling (Bonacci, et al., 2009). As well, triathletes need to dedicate time to each discipline often performing multiple disciplines in one day. The addition of RT may be challenging to incorporate into a triathlete's training due to time constraints over the course of a week or the demands that swimming, cycling, and running have.

Phase potentiation has been previously investigated but there is a need for a full description of the effects of this programming tactic with endurance athletes (Harris et al., 2000; Minetti et al., 2002; Zamparo et al., 2002). Bazyler et al., (2015) stated that "phase potentiation, is essential in the development of endurance-specific performance characteristics." Being able to effectively incorporate this training approach is needed alongside sport-specific training for triathletes.

Utilizing a phase potentiated approach to RT is commonly implemented in many sports. To the authors' knowledge, there are no previous studies that examine this method of conditioning with triathletes. The purpose of this study is to determine the effectiveness of an in-season RT program on improving measures of strength in female collegiate triathletes. This is to examine the changes in JH, peak force, and RFD when the volume and intensity variables of a RT program have been manipulated throughout multiple blocks/phases. The expected outcome is that the variables of JH and RFD will improve from pretesting to post-testing.

Methods

Experiential Approach to the Problem

The data were collected as part of an ongoing athlete monitoring program that has been established between the researcher's academic department and the university's athletic program. This process of data collection is standardized and the same procedures were followed during all testing sessions. All athletes participated in a pre-testing and post-testing session. Each experimental testing session was conducted at the same time of day.

Athletes

Nine female athletes (age = 19.2 ± 1.1 years, height = 166.5 ± 12.5 cm, body mass = 61.1 ± 9 kg) were reviewed in this study. All athletes performed in the same lifting program. *Table 3.1* illustrates the training age of the athletes in various aspects related to as well as triathlon. It should be noted that triathlon-specific training overlapped with that of the three competitive sports. After explaining the risks and benefits of the study, all athletes signed informed consent documents before participation in accordance with the Institutional Review Board of the university.

Table 3.1

Athlete Training Age

Athlete Training Age (in years)			
	Training Age within Competitive Sports		
Triathlon	Swim	Bike	Run
4.5±3.5	6±6	4±4	4±4

Procedures

Before the pre-testing session, athletes were familiarized with the protocol and how to properly how to perform static jumps (SJ), countermovement jump (CMJ), and isometric mid-thigh pull (IMTP).

The athletes completed two RT sessions per week (Wednesday and Friday) along with a midsection day between the RT sessions (Thursday). Both weekly RT and triathlon training sessions are included in *Table 3.2*. The training program consisted of two sequential summated microcycles (or blocks) with exercise selection for each day illustrated in Table 3.3.

Table 3.2

Weekly Triathlon Training Schedule

Triathlon Weekly Training Schedule Spring Term 2020							
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
AM	OFF		Swim	Swim	Swim	Swim	Cycling
AM	OFF						Run
PM	OFF	Cycling	Cycling	Run	Cycling	Run	
PM	OFF	Run		RT (heavy)	RT (light)	RT (heavy)	

*Schedule was consistent throughout the academic year

Table 3.3

Block Exercise Selection

	Basic Strength Block (weeks 7-9)	**Taper (weeks 10-12)**
Wednesday	Chest Pass Hop (Static), Depth Lands, Back Squat, Clean Grip Shoulder Press, Barbell RDL, and Dumbbell Bench Press	Chest Pass Hop static (3x3), Depth Jumps (3x3), Back Squat, Push Press, Drop Step Lunge to Box (2x4), and Incline Dumbbell Bench Press
Thursday	Plate Overhead A Walks, Seated Side Toss, Med Ball V Ups, and Supine Glute Bridges	Prone Bridge Med Ball Figure 8, Side Plank Clams, Med Ball Wood Chopper, and Supine Glute Bridges
Friday	Med Ball Toss for Height (3x3), Clean Pull, RDL to Bent-Over Row Complex, Clean Grip Mid-Thigh Pull, and Dumbbell Pitcher Pour (3x8)	Med Ball toss for height (3x3), Clean Pull, Clean Grip Countermovement Shrug, Plate Overhead Lateral Lunge, and Reverse Row

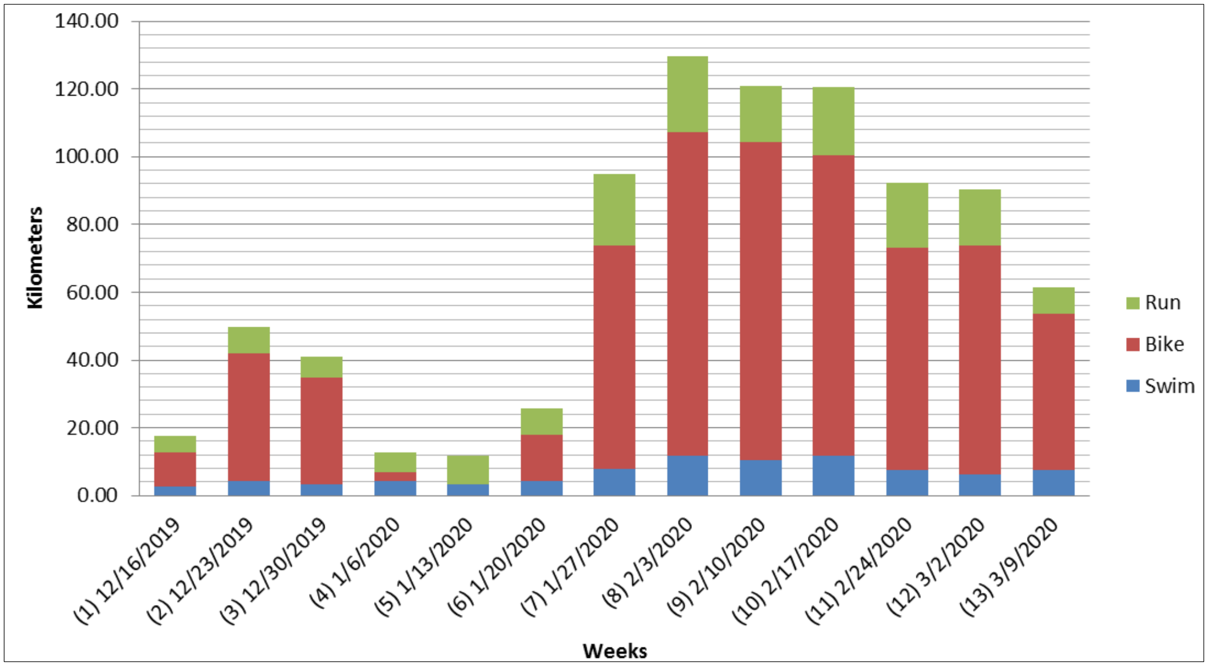
All testing sessions were completed at the same time of day and in the same order of tests. Testing sessions occurred on Friday during both week 6 and week 13.

Experimental Conditions

Before testing, all athletes were required to have a urine specific gravity (USG) < 1.20 to begin warm-up for testing. Once the USG test was passed, the athletes would perform the same standardized dynamic warm-up of 25 jumping jacks followed by 1x5 practice mid-thigh pulls (MTP) with 20kg, then 3x5 MPT with 40kg. Athletes would continue to jump testing which began with measuring SJ trials at 0, 11, and 20kg which progressed to CMJ using the same weights. All jump trials included at least 2 jumps at each weight and for each type of jump. This was followed by the IMTP with at least 2 pulls.

Figure 3.1

Triathlon Weekly Training Volume



Leading into the basic strength block of training and following a taper after their first competition, athletes all followed the same triathlon and RT program. Training loads were consistently tracked for triathlon-specific training on Training Peaks (*Figure 3.1*), which included distance traveled in swimming, cycling, and running over the week. Athletes also recorded their training loads lifted in the weight room on lifting sheets (see *Table 3.2* & *Table 3.4* for prescribed set x rep schemes and intensities). Intensity is calculated based on athlete subjectivity with suggested receptions in reserve being provided. The relative volume load depicted in *Table 3.4* is a product of average weekly intensity (1RM%) and total weekly repetitions. All groups completed the same RT program and testing routine.

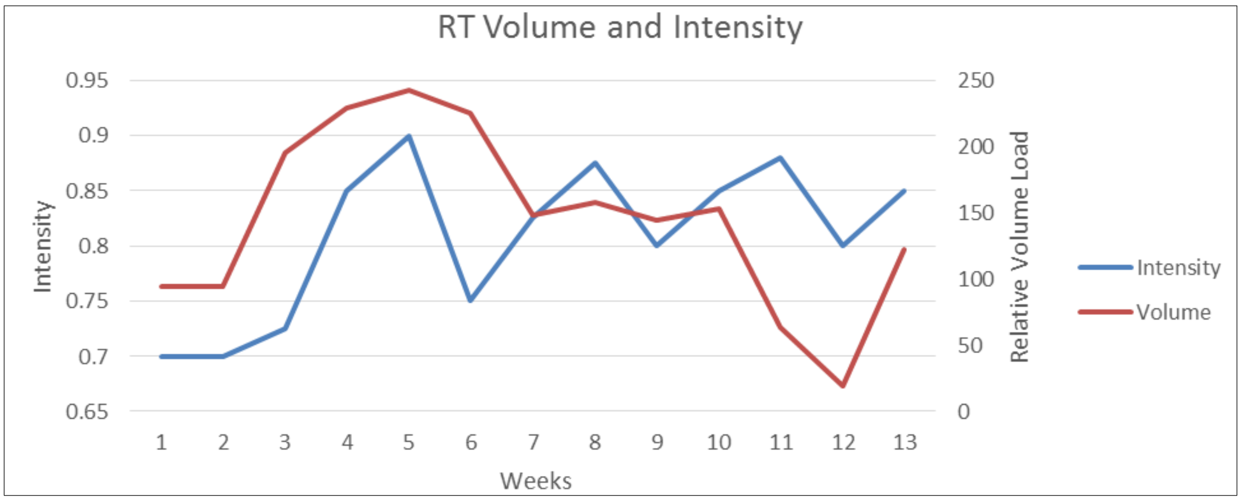
Table 3.4

Weekly Resistance Training Volume Load

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Sets	3	3	3	3	3	3	3	3	3	5	2	2	4
Reps	5	5	10	10	10	10	5	5	5	3	3	2	3
Intensity	70.0%	70.0%	72.5%	85.0%	90.0%	75.0%	82.5%	87.5%	80.0%	85.0%	88.0%	80.0%	85.0%
Relative Volume Load	94.5	94.5	195.75	229.5	243	225	148.5	157.5	144	153	63.36	19.2	122.4

Figure 3.2

Weekly Resistance Training Volume and Intensity



Athletes were instructed to follow the first 6 weeks of RT independently due to winter break taking place. Athletes were familiarized with the lifts and approach to RT before the beginning of the 6 weeks of independent RT. It should be noted that RT during this period was voluntary. Testing was then conducted before the start of the second block of training (basic strength) at the end of week 6. Testing included: hydration, anthropomorphic measurements, JH, isometric mid-thigh pull, and Athletics Shoulder (ASH) tests (which has no data that will be utilized in this study and was the final test performed during athlete monitoring).

Jump Testing

Jump testing was performed following a standard warm-up of 25 jumping jacks, 1x5 mid-thigh pulls with 20kg and 3x5 with 40kg. Athletes were assessed with 0 kg (polyvinyl chloride pipe), 10 kg (barbell), and 20 kg (barbell) weights The PVC pipe and barbell were used to eliminate arm swing and to standardize testing conditions between athletes. Athletes performed SJ from an internal knee angle of approximately 90° which was measured with the use of a goniometer. SJ followed a standardized warm-up and athletes performed two warm-up jumps for the unweighted SJ at 50% and 75% effort. Athletes then performed at least two SJ at 100% effort. Once completed, athletes began testing weighted jumps using the same procedure as the unweighted jumps. Unweighted and weighted CMJs were performed using the same procedures as SJ. If JH differences were greater than 2 cm, then additional trials were performed until two jumps were within 2 cm of each other.

Data were collected using dual force plates (2 x 91 cm x 45.5 116 cm force plates, RoughDeck HP, Rice Lake, WI) sampling at 1000 Hz. All data were simultaneously integrated into LabVIEW (version 7.1, National Instruments).

Isometric Mid-Thigh Pull

Participants were instructed to assume a posture body position identical to the start of the second pull of the clean with their torso upright, a knee angle of 125-135 degrees. A handheld goniometer was used to ensure that athletes assumed the required knee angle. Participants were required to fully extend the elbows, hold on to the bar with provided wrist straps, and then strapped to the bar with athletic tape to prevent grip from being a limiting factor. Practice pulls performed at 50% and 75% of maximum effort were done as a warm-up, these were separated by about 1 minute. Before participants were instructed to do the 100% pull, it was explained that they are to pull as “fast and as hard as you can”. The highest force generated during IMTP was reported as the absolute PF (mPF). As well, force at 120 ms, (Force120) and RFD at 0-120 (RFD 0-120) from the onset of pull were determined for each trial as values correspond with ground contact time during running. Lum et al., (2020) found that IMTP can be used as a means to assess muscular fitness in endurance runners and that the runner should focus on increasing maximum strength and RFD when performing RT to enhance their performance.

Data were collected using dual force plates (2 x 91 cm x 45.5 116 cm force plates, RoughDeck HP, Rice Lake, WI) sampling at 1000 Hz. All data were simultaneously integrated into LabVIEW (version 7.1, National Instruments).

Statistical Analysis

Data were analyzed using the statistical software JASP (JASP Version 0.14). A paired sample *t*-test was used to compare the variables: CMJ 0kg JH – FT, CMJ 20kg JH – FT, SJ 0kg JH – FT, SJ 20kg JH – FT, mRFD at 120ms, and mPeak Force. To correct for multiple comparisons, the Bonferroni correction was applied, with the alpha level of p was at 0.05.

Results

There was no significant difference in the variables that were measured. Two results that had diminished performances post-RT included CMJ 0kg JH - FT (m) and mRFD120 (N/s). Pre and post-p-value and Cohen's d are shown in *Table 3.5*. Descriptive data of mean and standard deviation (SD) are shown in *Table 3.6*.

Table 3.5

Pre vs Post Testing Statistical Significance

						95% CI for Cohen's *d*	
Measure 1		***t***	**df**	***p***	**Cohen's d**	**Lower**	**Upper**
CMJ 0kg JH - FT (m) Pre to Post Avg.	-	0.082	8	0.937	0.027	-0.627	0.680
CMJ 20kg JH - FT (m) Pre to Post Avg.	-	-0.872	8	0.409	-0.291	-0.950	0.386
SJ 0kg JH - FT (m) Pre to Post Avg.	-	-0.188	8	0.856	-0.063	-0.715	0.593
SJ 20kg JH - FT (m) Pre to Post Avg.	-	-1.391	8	0.202	-0.464	-1.141	0.239
mRFD120 (N/s) Pre to Post Avg.	-	0.672	8	0.521	0.224	-0.445	0.879
mPF (N) Pre to Post Avg.	-	-2.691	8	0.027	-0.897	-1.661	-0.095

Note. Student's t-test.
Significance set at $p < 0.0083$ via Bonferroni Correction

Table 3.6

Descriptives

	N	Mean	SD	SE
CMJ 0kg JH - FT (m) Pre	9	0.187	0.025	0.008
CMJ 0kg JH - FT (m) Post	9	0.186	0.019	0.006
CMJ 20kg JH - FT (m) Pre	9	0.116	0.024	0.008
CMJ 20kg JH - FT (m) Post	9	0.122	0.011	0.004
SJ 0kg JH - FT (m) Pre	9	0.170	0.033	0.011
SJ 0kg JH - FT (m) Post	9	0.172	0.020	0.007
SJ 20kg JH - FT (m) Pre	9	0.102	0.016	0.005
SJ 20kg JH - FT (m) Post	9	0.112	0.012	0.004
mRFD120 (N/s) Pre	9	2857.810	1858.382	619.461
mRFD120 (N/s) Post	9	2657.166	1559.954	519.985
mPF (N) Pre	9	2218.138	372.827	123.576
mPF (N) Post	9	2378.159	290.413	96.804

Discussion

With the data collection occurring for only 9 athletes, there was a very small pool of athletes, diminishing the effect size for this study. This means that if there were drastic differences with some participants on specific tests, it would have a significant impact on mean results. This reemphasizes the importance of examining individual results and especially doing so on smaller teams.

This study is the first to the authors' knowledge that has investigated the outcomes of an in-season RT program on measures of strength in female collegiate triathletes. The lifts selected for RT were incorporated to emphasize the movement specificity of each aspect of a triathlon (Zupan & Petosa 1995). The results from this study illustrated that despite improvements occurring in four of the tested areas, the improvements were not statistically significant. Beattie et al., (2014) had findings that illustrated how strength training is an effective means for improving movement economy, velocity at $\dot{V}O2max$, power output at $\dot{V}O2max$, maximal anaerobic running test velocity, and time trial performance. Previous training of the athletes included RT the semester before data collection as well as a RT program to be completed between semesters that consisted of a return to fitness block (2 weeks 3x5 between 70-75% effort) and strength endurance block (4 weeks 3x10 between 75-90% effort). The pre-test date occurred after athletes returned to campus and before the formal intervention of the RT program in the weight room. Post-testing took place after the athlete's first competition where a taper block was implemented leading up to the athletes' performance.

Where the mPF was the variable that saw the greatest improvement, it still did not meet the criteria to be considered statically significant. It is important to note that as peak force improves, the athletes will be able to perform submaximal movements either for longer or sustain a higher intensity for an equivalent duration that was previously performed at a lower force output. The reason for RFD becoming an important component alongside peak force is because this is the neuromuscular mechanism being activated quickly and efficiently enough to hit the required percentage of strength. The sooner this occurs, the sooner the needed force can be applied for the athlete's required task.

One limitation to the study was that the phase of training for sport-specific work was more intense during preparation for the competition which overlapped with the second data collection. Another limitation was the timeframe during which data collection took place. Due to the COVID-19 Pandemic, the duration of data collection was about half as long as what was originally planned. Studies that observed changes attributed to RT over a similar duration experienced mostly positive results related to improvements in variable measurement. Paton and Hopkins (2005) examined RT alongside improvements in cycling performance over 4-5 weeks of training. They concluded that CT was an effective means of improving endurance and sprint performance in their well-trained competitive athletes. These enhancements are attributed to improved exercise efficiency. Støren et al., (2008) examined well-trained distance runners over an 8-week intervention concluding that RE and increased time to exhaustion were improved with the inclusion of RT concurrently with their run training. RFD in the half squat improved from 466.7 ± 163.2 to 588.0 ± 147.9 (33.2%). This change in RFD is attributed to changes in recruitment patterns because of neural adaptation. 1RM in the squat also improved from 73.4 ±20.5 to 97.8 ±21.3 (26.0%). Squat strength has been strongly correlated to athletic movements that require relatively high-velocity, high-power outputs and RFD (Baker & Nance 1999). Weightlifting exercises utilized in the training session and their derivatives have shown a strong transfer of training to such movements as well (Arabatzi et al., 2010; Channell & Barfield 2008). An improved 1RM, in this context, may be attributed to increased muscle stiffness, a variable which for RE can become more efficient. Strength training is reported to positively impact musculotendinous unit stiffness by increasing their capabilities (Craib et al., 1996; Kubo et al., 2002; Millet et al., 2002). Elastic energy is stored more effectively in the series and parallel elastic component during eccentric muscle actions. This will then increase the concentric muscle force. As well, an increase in musculotendinous stiffness has a greater application to running than cycling because of the greater contribution of the stretch-shortening cycle (Rønnestad & Mujika 2013). Sunde et al., (2010) conducted a study on well-trained competitive cyclists which found improvements in work efficiency in both the control and intervention group, with the intervention group experiencing larger changes attributed to maximal strength training. The intervention group saw 1RM half-squat improve by 22.5 ±19.7 kg (13.5 % increase) and RFD in the half-squat improved by 134.0 ±171.6 W (16.7% increase). These changes led to improved CE, work efficiency in cycling, and time to exhaustion at maximal aerobic power. The authors stated that "the present study shows highly-significant correlation between pretest RDF in half squat and pretest CE", this again can be attributed to an optimal activation of motor neurons and muscle fibers post-intervention. Finally, Hoff et al., (2001) examined changes over 8 weeks in male cross country skiers and found reduced time to peak force and improved time to exhaustion. Again improvements to work economy changed significantly after the intervention of RT and maximal RT with an emphasis on neural adaptations improved strength (primarily RFD), leading to improved aerobic endurance performance via improved economy of movement. Many of these studies had subjects whose average age distribution was at least 10 years older than the participants in this study. As well, participants in other studies were often described as well trained, where some of the participants in this study range in their level of training from well trained to relatively untrained.

Longer studies, which ranged from 9-21 weeks in duration, examined the same variables or focused on the economy of movement in running and cycling. Paavolainen et al., (1999) utilized explosive strength training and examined improvements in RE by testing subjects in a 5k time trial. Over the 9 weeks of the study, significant changes were found in 5k running performance. These were suggested to be attributed to improvements in neuromuscular characteristics which transferred into improved power of the muscle and economy of movement. Millet et al., (2002) also found improvements to RE from concurrent RT with endurance running after a study that lasted 14 weeks in duration. Kelly et al., (2008) examined the effects concurrent strength and endurance training (RT that is performed along with sport-specific training, in this case running) would have on a group of recreational female endurance runners. There were greater improvements in 3k time trial results following the intervention on CT when compared to the endurance-only group and improvements in upper and lower body strength were present in the concurrent group, but these results were nonsignificant. However, between the two groups, there was no significant difference found in RE. It should be noted that there were no issues with the addition of RT and the outcomes of the endurance running program. Taipale et al., 2014) utilized mixed maximal and explosive exercises as the RT intervention concurrently with endurance running below lactate threshold over a 16-week study. CMJ was assessed and improvements were found 8 weeks into the study for male athletes and 12 weeks into the study for female subjects. Taipale et al., (2010) conducted another study on endurance runners where athletes completed a 6 week preparatory RT program before getting divided into maximal strength, explosive strength, and circuit training for 8 weeks. Both maximal strength (1RM) and CMJ in all groups, but the groups exposed to maximal strength and explosive strength training were more impacted by improvements to their strength and neuromuscular performance.

Mikkola et al., (2011) conducted a study that also consisted of a 6-week preparatory period followed by 8 weeks of specific programs for athletes: heavy resistance, explosive resistance, or muscle endurance training. Only the heavy RT group has significant improvements in CMJ height (from 28.4 ± 3.5 to 30.1 ± 3.9 cm), all the other groups did have some degree of improvement, however, it was not significant. It should be noted that this study was conducted with RT sessions occurring on different days than the endurance sessions. Aagaard et al., (2011) examined RT and the effects it had on endurance capacity and muscle fiber composition in young top-level cyclists over a 16-week duration. RFD was a measured variable that increased by 12-20% following CT, where the group that only performed endurance training experience no change in RFD. Häkkinen et al., (2003) concluded that over 21 weeks of training, the strength-endurance group showed significant increases in RFD. Finally, Glowacki et al., (2004) utilized a concurrent RT program with untrained male athletes over a 12-week study. Where there was no significant change in JH, the CT did not interfere with strength development but it was proposed that there could be a hindrance to the development of maximal aerobic capacity. Many of these studies had subjects whose average age distribution was within 10 years of participants in this study. As well, participants in other studies ranged from recreational to elite.

Endurance athletes who strength train with loads ≥70% 1RM will often achieve larger changes in movement economy and endurance performance than endurance athletes who strength train with lighter loads (Mikkola et al., 2007a; Sedano et al., 2013). Sedano et al. (2013) reported greater magnitudes of change in RE, CMJ height, v$\dot{V}$O2max, and 3-km time trial performance after 12 weeks of heavy strength training (70% 1RM) (Bazyler et al., 2015). A sequenced approach may be more appropriate than trying to improve strength, power, and endurance simultaneously (Bazyler et al., 2015). Changes that occur due to RT are initially a result of neuromuscular adaptation when strength is increased (Aagaard et al, 2002) and it often takes at minimum found that 8 weeks of concurrent RT and endurance training improved endurance and selective neuromuscular performance measures (Mikkola et al., 2011). Manipulating volume and intensity over an appropriate duration (≥8 weeks loading) (Bishop et al., 1999; Bastiaans et al., 2001; Levin et al., 2009) is needed for long-term endurance performance to improve.

JH from other studies Guglielmo (et al. 2008) found that after only 4 weeks of concurrent running and heavy strength training (3–5 sets at 6RM loads), there were larger magnitudes of change in RE, 1RM strength, and CMJ height compared with concurrent running and lighter strength training (3–5 sets at 12RM loads) in middle- and long-distance runners who competed at the regional and national level (Bazyler et al., 2015). Piacentini et al., (2013) examined master endurance runners after a 7 week RT intervention in which SJ and CMJ were collected pre and post-intervention. CMJ was 21.8 ± 3.9 pre and 22.5 ± 4.0 post interventions (a 3% improvement). SJ was 20.0 ± 3.4 pre and 22.2 ± 3.3 post interventions (a 11% improvement). Mikkola et al., (2011) heavy RT group of male recreation runners had their CMJ height improve from 28.4 ± 3.5 to 30.1 ± 3.9 cm post-intervention. Taipale et al., (2014) examined both male and female athletes and over a 16-week intervention, there were significant improvements in male CMJ performance from weeks 0- 8 and 8-12. Glowacki et al., (2004) examined untrained male volunteers over 12 weeks and despite there being no significant changes to athlete vertical JH, this may be attributed to an increase in the lean body mass athletes in both the CT group experienced throughout the study.

Again, RFD is an important variable since it is the neuromuscular activation that limits how quickly force may be produced (Aagaard et al, 2002; Mikkola et al., 2011). When maximal strength training is utilized, with emphasis on neural adaptations, improves in strength, particularly RFD, and improves aerobic endurance by improved work economy are also experienced (Hoff et al., 2001). This implies that as RFD improves so will aspects of movement economy that will benefit the endurance component of sports like distance running, distance cycling, and triathlon. Aagaard et al., (2010) found a 12-20% increase in max muscle strength and RFD in response to a 16-week concurrent strength endurance program in top-level cyclists. Støren et al., (2008) examined well-trained distance runners over an 8-week intervention concluding that RE and increased time to exhaustion were improved with the inclusion of RT concurrently with their run training. RFD in the half squat improved from 466.7 ± 163.2 to 588.0 ± 147.9 (33.2%).

Practical Application

This study might provide insight into the structuring and implementation of phase potentiation. When developing a RT program alongside an endurance program, it is essential to focus on specific aspects during different points in time but allowing what was previously conditioned to build the foundation for future adaptations. This study examines the potential changes in performance indicators that are attributed to RT. Therefore, a phase potentiated approach to RT can provide enhanced RFD and JH when appropriate intensities are utilized and progressions are implemented. Athletes who have a young training age relative to RT will take time to effectively apply intent tot their lifting sessions and use 100% efforts during testing sessions. Sport specific sessions need to also be coordinated in an effective manner to allow for adequate rest leading up to the RT session. There will often be time constrains between the athlete’s academic, social, and sport specific training so appropriately scheduling a RT session amongst other obligations can be a challenge depending on the level you are competing at.

Coaches may consider applying this approach to their RT to maximize their athletes' performances leading into championship events or competitions of great importance.

References

Aagaard, P., Andersen, J. L., Bennekou, M., Larsson, B., Olesen, J. L., Crameri, R., & Kjaer, M. (2011). Effects of resistance training on endurance capacity and muscle fiber composition in young top-level cyclists. *Scandinavian Journal of Medicine & Science in Sports*, *21*(6).

Aagaard, P., Simonsen, E. B., Andersen. J. L., Magnusson , P., & Dyhre-Poulsen. P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol (1985).93*(4):1318-1326.

Andersen, L. L., Andersen, J. L., Zebis, M. K., & Aagaard, P. (2010). Early and late rate of force development: Differential adaptive responses to resistance training? *Scandinavian Journal of Medicine & Science in Sports, 20*(1). doi:10.1111/j.1600-0838.2009.00933.x

Arabatzi, F., Kellis, E., & Saèz-Saez De Villarreal, E. (2010). Vertical jump biomechanics after plyometric, weight lifting, and combined (weight lifting + plyometric) training. *Journal of Strength and Conditioning Research, 24*(9), 2440-2448.

Baker, D., & Nance, S. (1999). The relation between running speed and measures of strength and power in professional rugby league players. *Journal of Strength and Conditioning Research*, *13*(3), 230-235.

Bastiaans, J., Diemen, A., Veneberg, T., & Jeukendrup, A. (2001). The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists. *European Journal of Applied Physiology*, *86*(1), 79–84. https://doi.org/10.1007/s004210100507

Bazyler, C. D., Abbott, H. A., Bellon, C. R., Taber, C. B., & Stone, M. H. (2015). Strength training for endurance athletes. *Strength & Conditioning Journal*, *37*(2), 1-12.

Beattie, K., Kenny, I. C., Lyons, M., & Carson, B. P. (2014). The effect of strength training on performance in endurance athletes. *Sports Medicine, 44*(6), 845-865. doi:10.1007/s40279-014-0157-y

Bishop, D., Jenkins, D. G., Mackinnon, L. T., Mceniery, M., & Carey, M. F. (1999). The effects of strength training on endurance performance and muscle characteristics. *Medicine & Science in Sports & Exercise, 31*(6), 886-891.

Bonacci, J., Chapman, A., Blanch, P., & Vicenzino, B. (2009). Neuromuscular adaptations to training, injury, and passive interventions. *Sports Medicine, 39*(11), 903-921.

Byrne, P. J., Moody, J. A., Cooper, S., Farrell, E., & Kinsella, S. (2020). Short-Term effects of “composite” training on strength, jump, and sprint performance in hurling players. *Journal of Strength and Conditioning Research, Publish Ahead of Print*. doi:10.1519/jsc.0000000000003820

Channell, B. T., & Barfield, J. P. (2008). Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. *Journal of Strength and Conditioning Research, 22*(5), 1522-1527.

Craib, M. W., Mitchell, V. A., Fields, K. B., Cooper, T. R., Hopewell, R., & Morgan, D. W. (1996). The association between flexibility and running economy in sub-elite male distance runners. *Medicine & Science in Sports & Exercise, 28*(6), 737-743.

DeWeese, B., Hornsby, G., Stone, M., & Stone, M. (2015a). The training process: Planning for strength—power training in track and field. Part 1: Theoretical aspects. *Journal of Sport and Health Science*. 4. 10.1016/j.jshs.2015.07.003.

García-Pinillos, F., Cámara-Pérez, J. C., González-Fernández, F. T., Párraga-Montilla, J. A., Muñoz-Jiménez, M., & Latorre-Román, P. Á. (2016). Physiological and neuromuscular response to a simulated sprint-distance triathlon. *Journal of Strength and Conditioning Research, 30*(4), 1077-1084. doi:10.1519/jsc.0000000000001172

Glowacki, S. P., Martin, S. E., Maurer, A., Baek, W., Green, J. S., & Crouse, S. F. (2004). Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine & Science in Sports & Exercise*, 2119-2127. doi:10.1249/01.mss.0000147629.74832.52

Häkkinen, K., Alen, M., Kraemer, W. J., Gorostiaga, E., Izquierdo, M., Rusko, H., Mikkola, J., Häkkinen, A., Valkeinen, H., Kaarakainen, E., Romu, S., Erola, V., Ahtiainen, J., & Paavolainen, L. (2003). Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *European Journal of Applied Physiology*, *89*(1), 42–52. https://doi.org/10.1007/s00421-002-0751-9

Harris. G. R., Stone. M. H., O'Bryant. H. S., Proulx. C. M., & Johnson. R. L. (2000). Short-term performance effects of high power, high force, or combined weight training methods. *J Strength Cond Res* 14: 14–20.

Hoff, J. (2001). Maximal strength training enhances running economy and aerobic endurance performance. *Medicine & Science in Sports & Exercise, 33*(5).

Kelly, C. M., Burnett, A. F., & Newton, M. J. (2008). The effect of strength training on three-kilometer performance in recreational women endurance runners. *Journal of Strength and Conditioning Research, 22*(2), 396-403. doi:10.1519/jsc.0b013e318163534a

Kons, R. L., Ache-Dias, J., Detanico, D., Barth, J., & Dal Pupo, J. (2018). Is vertical jump height an indicator of athletes' power output in different sport modalities? *Journal of Strength and Conditioning Research, 32*(3), 708-715. doi:10.1519/jsc.0000000000001817

Kraemer, W. J., Hakkinen, K., Travis Triplett-Mcbride, N., Fry, A. C., Perry Koziris, L., Ratamess, N. A., & Knuttgen, H. G. (2003). Physiological changes with periodized resistance training in women tennis players. *Medicine & Science in Sports & Exercise, 35*(1), 157-168. doi:10.1097/00005768-200301000-00024

Kubo, K., Kanehisa, H., & Fukunaga, T. (2002). Effects of transient muscle contractions and stretching on the tendon structures in vivo. *Acta Physiologica Scandinavica, 175*(2), 157-164. doi:10.1046/j.1365-201x.2002.00976.x

Levin, G. T., Mcguigan, M. R., & Laursen, P. B. (2009). Effect of concurrent resistance and endurance training on physiologic and performance parameters of well-trained endurance cyclists. *Journal of Strength and Conditioning Research, 23*(8), 2280-2286.

Lum, D., Chua, K., & Rashid Aziz, A. (2020). Isometric mid-thigh pull force-time characteristics: A good indicator of running performance. *Journal of Trainology, 9*(2), 54-59. doi:10.17338/trainology.9.2_54

Mangine, G. T., Hoffman, J. R., Wang, R., Gonzalez, A. M., Townsend, J. R., Wells, A. J., & Stout, J. R. (2016). Resistance training intensity and volume affect changes in rate of force development in resistance-trained men. *European Journal of Applied Physiology, 116*(11-12), 2367-2374. doi:10.1007/s00421-016-3488-6

Mikkola, J. S., Rusko, H. K., Nummela, A. T., Paavolainen, L. M., & Häkkinen, K. (2007). concurrent endurance and explosive type strength training increases activation and fast force production of leg extensor muscles in endurance athletes. *The Journal of Strength and Conditioning Research, 21*(2), 613.

Mikkola, J., Rusko, H., Nummela, A., Pollari, T., & Häkkinen, K. (2007). Concurrent endurance and explosive type strength training improves neuromuscular and anaerobic characteristics in young distance runners. *International Journal of Sports Medicine, 28*(7), 602-611. doi:10.1055/s-2007-964849

Mikkola, J., Vesterinen, V., Taipale, R., Capostagno, B., Häkkinen, K., & Nummela, A. (2011). Effect of resistance training regimens on treadmill running and neuromuscular performance in recreational endurance runners. *Journal of Sports Sciences, 29*(13), 1359-1371. doi:10.1080/02640413.5011.589467

Millet, G. P., Jaouen, B., Borrani, F., & Candau, R. (2002). Effects of concurrent endurance and strength training on running economy and & VO2 kinetics. *Medicine & Science in Sports & Exercise, 34*(8), 1351-1359.

Minetti, A. E. (2002). On the mechanical power of joint extensions as affected by the change in muscle force (or cross-sectional area), ceteris paribus. Eur J Appl Physiol 86: 363–369, 2002.

Noakes, T. D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medicine and Science in Sports*, *10*(3), 123-145. doi:10.1034/j.1600-0838.2000.010003123.x

Paavolainen, L., Hakkinen, K., Hamalainen, I., Nummela, A., & Rusko, H. (2003). Explosive-strength training improves 5-km running time by improving running economy and muscle power. *Scandinavian Journal of Medicine & Science in Sports*, *13*(4), 272–272. https://doi.org/10.1034/j.1600-0838.2003.00340.x

Paton, C. D., & Hopkins, W. G. (2005). Combining explosive and high-resistance training improves performance in competitive cyclists. *Journal of Strength and Conditioning Research, 19*(4), 826-830. doi:10.1519/00124278-200511000-00017

Rønnestad, B. R., & Mujika, I. (2013). Optimizing strength training for running and cycling endurance performance: A review. *Scandinavian Journal of Medicine & Science in Sports, 24*(4), 603-612. doi:10.1111/sms.12104

Sedano, S., Marín, P. J., Cuadrado, G., & Redondo, J. C. (2013). Concurrent training in elite male runners. *Journal of Strength and Conditioning Research, 27*(9), 2433-2443. doi:10.1519/jsc.0b013e318280cc26

Stone, M. H., Sands, W. A., & Stone, M. E. (2007). Principles and practice of strength-power training. *Champaign, IL: Human Kinetics*, 176.

Støren, Ø, Helgerud, J., Støa, E. M., & Hoff, J. (2008). Maximal strength training improves running economy in distance runners. *Medicine & Science in Sports & Exercise, 40*(6), 1087-1092.

Taipale, R. S., Mikkola, J., Salo, T., Hokka, L., Vesterinen, V., Kraemer, W. J., & Häkkinen, K. (2014). Mixed maximal and explosive strength training in recreational endurance runners. *Journal of Strength and Conditioning Research, 28*(3), 689-699. doi:10.1519/jsc.0b013e3182a16d73

Taipale, R., Mikkola, J., Nummela, A., Vesterinen, V., Capostagno, B., Walker, S., & Häkkinen, K. (2010). Strength training in endurance runners. *International Journal of Sports Medicine, 31*(07), 468-476. doi:10.1055/s-0029-1243639

Tanaka, H., & Swensen, T. (1998). Impact of resistance training on endurance performance. *Sports Medicine, 25*(3), 191-200.

Zamparo. P., Minetti. A. E., & di Prampero P. E. (2002). Interplay among the changes of muscle strength, cross-sectional area and maximal explosive power: Theory and facts. *European Journal of Applied Physiology, 88*(3), 193-202. doi:10.1007/s00421-002-0691-4

Zupan, M. F., & Scott Petosa, P. (1995). Aerobic and resistance cross-training for peak triathlon performance. *Strength and Conditioning Journal, 17*(5), 7. doi:10.1519/1073-6840(1995)0172.3.co;2

Chapter 4. Summary and Future Investigations

The purpose of this study is to determine the effectiveness of an in-season RT program on improving measures of strength in female collegiate triathletes. To the author's knowledge, this is the only study that has investigated a phase potentiated approach to RT for triathletes. The results from this study yielded no statistical significance ($p<0.0083$) despite minor improvements to many of the tested variables. Testing occurred seven weeks apart, which is often around the time for neuromuscular changes to take place but not necessarily any physiological adaptations. The results of this study expand upon the findings of previous studies by providing a complete description of the training of sport-specific and RT volume as well as RT intensity and exercise leading up to data collection and through the conclusion of collection.

Where there were no significant improvements across the average of the athletes, it is still worthwhile to examine individual results. Since triathlon is an individual sport, athletes will have specific foci to improve in a particular discipline or overall in the execution of a race. So examining changes in variables for each individual is an important step towards making specific decisions to improve the performance of each athlete. Factors such as JH, RFD, and PF are important to examine when relating them to the economy of movement for cycling and running and will be attributed more to RT instead of any of the discipline-specific conditioning they are participating in.

When examining results from a phase potentiated program, it is beneficial to obtain measurements of that program's effectiveness before the intervention, during the intervention, and after the intervention. Due to restraints of an academic schedule and COVID-19 pandemic, no monitoring occurred before the athlete's first block of RT, and follow-up monitoring sessions were unable to be conducted past mid-March. This study began collecting data 6 weeks into the athletes' RT program. Collecting monitoring data before the intervention of any program is a recommended means of establishing a baseline.

While the duration of data collection was shortened, it reemphasized the window of time it takes for adaptations to take place. Future studies dealing with the effects of phase potentiation should examine variables at the end of each block when the down week occurs. This allows for consistent monitoring of changes attributed to RT as well as sport-specific adaptations if additional monitoring tests are selected. It is always important to keep in mind the window of adaptations since neural, tendon, cardiovascular, and muscular adaptations all occur at varying rates (especially at different stages of human development), with neural adaptations occurring first which influence movement patterns.

Additionally, this study was conducted with a group of athletes who had just begun their athlete monitoring program. Familiarizing participants in an athlete monitoring program with the tests that are being conducted is an effective way for acquiring reliable results and comparing future results.

References

Aagaard, P., & Andersen, J. L. (2010). Effects of strength training on endurance capacity in top-level endurance athletes. *Scandinavian Journal of Medicine & Science in Sports, 20*, 39-47.

Aagaard, P., Andersen, J. L., Bennekou, M., Larsson, B., Olesen, J. L., Crameri, R., & Kjaer, M. (2011). Effects of resistance training on endurance capacity and muscle fiber composition in young top-level cyclists. *Scandinavian Journal of Medicine & Science in Sports*, *21*(6).

Aagaard, P., Simonsen, E. B., Andersen. J. L., Magnusson , P., & Dyhre-Poulsen. P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *J Appl Physiol (1985).93*(4):1318-1326.

Andersen, L. L., Andersen, J. L., Zebis, M. K., & Aagaard, P. (2010). Early and late rate of force development: Differential adaptive responses to resistance training? *Scandinavian Journal of Medicine & Science in Sports*, *20*(1). doi:10.1111/j.1600-0838.2009.00933.x

Arabatzi, F., Kellis, E., & Saèz-Saez De Villarreal, E. (2010). Vertical jump biomechanics after plyometric, weight lifting, and combined (weight lifting + plyometric) training. *Journal of Strength and Conditioning Research*, *24*(9), 2440-2448.

Abernethy, P. J., Barry, B. K., & Logan, P. A. (1999). Concurrent strength and endurance training [Abstract]. *Sports Medicine*, *28*(6), 413-427.

Baker, D., & Nance, S. (1999). The relation between running speed and measures of strength and power in professional rugby league players. *Journal of Strength and Conditioning Research, 13*(3), 230-235.

Barker, Leland A., Harry, John R., & Mercer, John A. (2018). Relationships between countermovement jump ground reaction forces and jump height, reactive strength index, and jump time, *Journal of Strength and Conditioning Research, 32*(1), 248-254. doi:10.1519/jsc.0000000000002160

Bastiaans, J., Diemen, A., Veneberg, T., & Jeukendrup, A. (2001). The effects of replacing a portion of endurance training by explosive strength training on performance in trained cyclists. *European Journal of Applied Physiology*, *86*(1), 79–84. https://doi.org/10.1007/s004210100507

Bazyler, C. D., Abbott, H. A., Bellon, C. R., Taber, C. B., & Stone, M. H. (2015). Strength training for endurance athletes. *Strength & Conditioning Journal, 37*(2), 1-12.

Beattie, K., Kenny, I. C., Lyons, M., & Carson, B. P. (2014). The effect of strength training on performance in endurance athletes. *Sports Medicine*, *44*(6), 845-865. doi:10.1007/s40279-014-0157-y

Bishop, D., Jenkins, D. G., Mackinnon, L. T., Mceniery, M., & Carey, M. F. (1999). The effects of strength training on endurance performance and muscle characteristics. *Medicine & Science in Sports & Exercise, 31*(6), 886-891.

Bonacci, J., Chapman, A., Blanch, P., & Vicenzino, B. (2009). Neuromuscular adaptations to training, injury, and passive interventions. *Sports Medicine, 39*(11), 903-921.

Bosquet. L., Montpeti. J., Arvisais. D., & Mujika, I (2007). Effects of tapering on performance: A meta-analysis. *Journal of the American College of Sports Medicine*. 8:1358-1365 2007.

Byrne, P. J., Moody, J. A., Cooper, S., Farrell, E., & Kinsella, S. (2020). Short-Term effects of "composite" training on strength, jump, and sprint performance in hurling players. *Journal of Strength and Conditioning Research, Publish Ahead of Print*. doi:10.1519/jsc.0000000000003820

Channell, B. T., & Barfield, J. P. (2008). Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. *Journal of Strength and Conditioning Research, 22*(5), 1522-1527.

Craib, M. W., Mitchell, V. A., Fields, K. B., Cooper, T. R., Hopewell, R., & Morgan, D. W. (1996). The association between flexibility and running economy in sub-elite male distance runners. *Medicine & Science in Sports & Exercise, 28*(6), 737-743.

DeWeese, B., Hornsby, G., Stone, M., & Stone, M. (2015a). The training process: Planning for strength—power training in track and field. Part 1: Theoretical aspects. *Journal of Sport and Health Science*. 4. 10.1016/j.jshs.2015.07.003.

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015b). The training process: Planning for strength–power training in track and field. Part 2: Practical and applied aspects. *Journal of Sport and Health Science, 4*(4), 318-324. doi:10.1016/j.jshs.2015.07.002

Doma, K., Deakin, G. B., & Bentley, D. J. (2017). Implications of impaired endurance performance following single bouts of resistance training: An alternate concurrent training perspective. *Sports Medicine, 47*(11), 2187-2200. doi:10.1007/s40279-017-0758-3

García-Pinillos, F., Cámara-Pérez, J. C., González-Fernández, F. T., Párraga-Montilla, J. A., Muñoz-Jiménez, M., & Latorre-Román, P. Á. (2016). Physiological and neuromuscular response to a simulated sprint-distance triathlon. *Journal of Strength and Conditioning Research, 30*(4), 1077-1084. doi:10.1519/jsc.0000000000001172

Glowacki, S. P., Martin, S. E., Maurer, A., Baek, W., Green, J. S., & Crouse, S. F. (2004). Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine & Science in Sports & Exercise*, 2119-2127. doi:10.1249/01.mss.0000147629.74832.52

Guglielmo, L., Greco, C., & Denadai, B. (2008). Effects of strength training on running economy. *International Journal of Sports Medicine, 30*(01), 27-32. doi:10.1055/s-2008-1038792

Hancock, A. P., Sparks, K. E., & Kullman, E. L. (2015). Postactivation potentiation enhances swim performance in collegiate swimmers. *Journal of Strength and Conditioning Research, 29*(4), 912-917.

Harris. G. R., Stone. M. H., O'Bryant. H. S., Proulx. C. M., & Johnson. R. L. (2000). Short-term performance effects of high power, high force, or combined weight training methods. *J Strength Cond Res* 14: 14–20.

Hickson, R. C., Dvorak, B. A., Gorostiaga, E. M., Kurowski, T. T., & Foster, C. (1988). Potential for strength and endurance training to amplify endurance performance. *Journal of Applied Physiology, 65*(5), 2285-2290.

Hoff, J. (2001). Maximal strength training enhances running economy and aerobic endurance performance. *Medicine & Science in Sports & Exercise*, *33*(5).

Hokka, L., Vesterinen, V., Kraemer, W. J., & Häkkinen, K. (2014). Mixed maximal and explosive strength training in recreational endurance runners. *Journal of Strength and Conditioning Research, 28*(3), 689-699.

Houmard, J. A., B. K. Scott, C. L. Justice, & T. C. Chenier. (1994). The effects of taper on performance in distance runners. *Med. Sci. Sports Exerc*. 26:624–631, 1994.

Issurin, V. (2008). Block periodization versus traditional training theory: A review. *The Journal of sports medicine and physical fitness*. 48. 65-75.

Mäestu, J., Jürimäe, J., & Jürimäe, T. (2003). Effect of heavy increase in Training stress on the plasma Leptin concentration in highly trained male rowers. *Hormone Research in Paediatrics, 59*(2), 91-94. doi:10.1159/000068577

Kelly, C. M., Burnett, A. F., & Newton, M. J. (2008). The effect of strength training on three-kilometer performance in recreational women endurance runners. *Journal of Strength and Conditioning Research, 22*(2), 396-403. doi:10.1519/jsc.0b013e318163534a

Kons, R. L., Ache-Dias, J., Detanico, D., Barth, J., & Dal Pupo, J. (2018). Is vertical jump height an indicator of athletes' power output in different sport modalities? *Journal of Strength and Conditioning Research, 32*(3), 708-715. doi:10.1519/jsc.0000000000001817

Kraemer, W. J., Hakkinen, K., Travis Triplett-Mcbride, N., Fry, A. C., Perry Koziris, L., Ratamess, N. A., & Knuttgen, H. G. (2003). Physiological changes with periodized resistance training in women tennis players. *Medicine & Science in Sports & Exercise, 35*(1), 157-168. doi:10.1097/00005768-200301000-00024

Kubo, K., Kanehisa, H., & Fukunaga, T. (2002). Effects of transient muscle contractions and stretching on the tendon structures in vivo. *Acta Physiologica Scandinavica, 175*(2), 157-164. doi:10.1046/j.1365-201x.2002.00976.x

Leveritt, M., Abernethy, P. J., Barry, B. K., & Logan, P. A. (1999). Concurrent strength and endurance training. *Sports Medicine, 28*(6), 413-427. doi:10.2165/00007256-199928060-00004

Leveritt, M., Abernethy, P., Barry, B., & Logan, P. (2003). Concurrent strength and endurance training, *Journal of Strength and Conditioning Research*: August 2003 - Volume 17 - Issue 3 - p 503-508

Levin, G. T., Mcguigan, M. R., & Laursen, P. B. (2009). Effect of concurrent resistance and endurance training on physiologic and performance parameters of well-trained endurance cyclists. *Journal of Strength and Conditioning Research, 23*(8), 2280-2286.

Lum, D., Chua, K., & Rashid Aziz, A. (2020). Isometric mid-thigh pull force-time characteristics: A good indicator of running performance. *Journal of Trainology, 9*(2), 54-59. doi:10.17338/trainology.9.2_54

Mangine, G. T., Hoffman, J. R., Wang, R., Gonzalez, A. M., Townsend, J. R., Wells, A. J., & Stout, J. R. (2016). Resistance training intensity and volume affect changes in rate of force development in resistance-trained men. *European Journal of Applied Physiology, 116*(11-12), 2367-2374. doi:10.1007/s00421-016-3488-6

Margaritis, I., Palazzetti, S., Rousseau, A., Richard, M., & Favier, A. (2003). Antioxidant supplementation and tapering exercise improve exercise-induced antioxidant response. *Journal of the American College of Nutrition, 22*(2), 147-156. doi:10.1080/07315724.2003.10719288

Mikkola, J. S., Rusko, H. K., Nummela, A. T., Paavolainen, L. M., & Häkkinen, K. (2007). concurrent endurance and explosive type strength training increases activation and fast force production of leg extensor muscles in endurance athletes. *The Journal of Strength and Conditioning Research, 21*(2), 613.

Mikkola, J., Rusko, H., Nummela, A., Pollari, T., & Häkkinen, K. (2007). Concurrent endurance and explosive type strength training improves neuromuscular and anaerobic characteristics in young distance runners. *International Journal of Sports Medicine, 28*(7), 602-611. doi:10.1055/s-2007-964849

Mikkola, J., Vesterinen, V., Taipale, R., Capostagno, B., Häkkinen, K., & Nummela, A. (2011). Effect of resistance training regimens on treadmill running and neuromuscular performance in recreational endurance runners. *Journal of Sports Sciences, 29*(13), 1359-1371. doi:10.1080/02640413.5011.589467

Millet, G. P., Jaouen, B., Borrani, F., & Candau, R. (2002). Effects of concurrent endurance and strength training on running economy and & VO2 kinetics. *Medicine & Science in Sports & Exercise, 34*(8), 1351-1359.

Minetti, A. E. (2002). On the mechanical power of joint extensions as affected by the change in muscle force (or cross-sectional area), ceteris paribus. Eur J Appl Physiol 86: 363–369, 2002.

Mujika, I., & Padilla, S. (2003). Scientific bases for precompetition tapering strategies. *Medicine & Science in Sports & Exercise, 35*(7), 1182-1187. doi:10.1249/01.mss.0000074448.73931.11

Mujika, I., Chatard, J., & Geyssant, A. (1996). Effects of training and taper on blood leucocyte populations in competitive swimmers: Relationships with cortisol and performance. *International Journal of Sports Medicine, 17*(03), 213-217. doi:10.1055/s-2007-972834

Neary, J. P., Martin, T. P., & Quinney, H. A. (2003). Effects of taper on endurance cycling capacity and single muscle fiber properties. *Medicine & Science in Sports & Exercise, 35*(11), 1875-1881. doi:10.1249/01.mss.0000093617.28237.20

Neary, J. P., Martin, T. P., Reid, D. C., Burnham, R., & Quinney, H. A. (1992). The effects of a reduced exercise duration taper programme on performance and muscle enzymes of endurance cyclists. *European Journal of Applied Physiology and Occupational Physiology, 65*(1), 30-36. doi:10.1007/bf01466271

Noakes, T. D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medicine and Science in Sports, 10*(3), 123-145. doi:10.1034/j.1600-0838.2000.010003123.x

Paavolainen, L., Hakkinen, K., Hamalainen, I., Nummela, A., & Rusko, H. (2003). Explosive-strength training improves 5-km running time by improving running economy and muscle power. *Scandinavian Journal of Medicine & Science in Sports*, *13*(4), 272–272. https://doi.org/10.1034/j.1600-0838.2003.00340.x

Painter, K. B., Haff, G. G., Ramsey, M. W., Mcbride, J., Triplett, T., Sands, W. A., & Stone, M. H. (2012). Strength gains: Block versus daily undulating periodization weight training among track and field athletes. *International Journal of Sports Physiology and Performance, 7*(2), 161-169. doi:10.1123/ijspp.7.2.161

Paton, C. D., & Hopkins, W. G. (2005). Combining explosive and high-resistance training improves performance in competitive cyclists. *Journal of Strength and Conditioning Research, 19*(4), 826-830. doi:10.1519/00124278-200511000-00017

Piacentini, M. F., De Ioannon, G., Comotto, S., Spedicato, A.,Vernillo, G.,La Torre, A., (2013). Concurrent strength and endurance training effects on running economy in master endurance runners, *Journal of Strength and Conditioning Research*: August 2013 - Volume 27 - Issue 8 - p 2295-230 DOI: 10.1519/JSC.0b013e3182794485

Plisk, S. S., & Stone, M. H. (2003). Periodization strategies. *Strength and Conditioning Journal, 25*(6), 19-37. doi:10.1519/00126548-200312000-00005

Rønnestad, B. R., & Mujika, I. (2013). Optimizing strength training for running and cycling endurance performance: A review. *Scandinavian Journal of Medicine & Science in Sports, 24*(4), 603-612. doi:10.1111/sms.12104

Sedano, S., Marín, P. J., Cuadrado, G., & Redondo, J. C. (2013). Concurrent training in elite male runners. *Journal of Strength and Conditioning Research*, *27*(9), 2433-2443. doi:10.1519/jsc.0b013e318280cc26

Sparto, P. J., Parnianpour, M., Reinsel, T. E., & Simon, S. (1997). The effect of fatigue on multijoint kinematics, coordination, and postural stability during a repetitive lifting test. *Journal of Orthopaedic & Sports Physical Therapy*, *25*(1), 3-12. doi:10.2519/jospt.1997.25.1.3

Stone, M. H., Sands, W. A., & Stone, M. E. (2007). Principles and practice of strength-power training. *Champaign, IL: Human Kinetics*, 176.

Støren, Ø, Helgerud, J., Støa, E. M., & Hoff, J. (2008). Maximal strength training improves running economy in distance runners. *Medicine & Science in Sports & Exercise, 40*(6), 1087-1092.

Suchomel, T. J., Nimphius, S., Bellon, C. R., & Stone, M. H. (2018). The importance of muscular strength: Training considerations. *Sports Medicine*, *48*(4), 765-785. doi:10.1007/s40279-018-0862-z

Sunde, A., Støren, Ø., Bjerkaas, M., Larsen, M. H., Hoff, J., & Helgerud, J. (2010). Maximal strength training improves cycling economy in competitive cyclists, *Journal of Strength and Conditioning Research*: August 2010 - Volume 24 - Issue 8 - p 2157-2165 doi: 10.1519/JSC.0b013e3181aeb16a

Taipale, R. S., Mikkola, J., Salo, T., Hokka, L., Vesterinen, V., Kraemer, W. J., & Häkkinen, K. (2014). Mixed maximal and explosive strength training in recreational endurance runners. *Journal of Strength and Conditioning Research, 28*(3), 689-699. doi:10.1519/jsc.0b013e3182a16d73

Taipale, R., Mikkola, J., Nummela, A., Vesterinen, V., Capostagno, B., Walker, S., & Häkkinen, K. (2010). Strength training in endurance runners. *International Journal of Sports Medicine, 31*(07), 468-476. doi:10.1055/s-0029-1243639

Tanaka, H., Costill, D. L., Thomas, R., Fink, W. J., & Widrick, J. J. (1993). Dry-land resistance training for Competitive Swimming. *Medicine & Science in Sports & Exercise, 25*(8).

Tanaka, H., & Swensen, T. (1998). Impact of resistance training on endurance performance. *Sports Medicine, 25*(3), 191-200.

Triscott, S., Gordon, J., Kuppuswamy, A., King, N., Davey, N., & Ellaway, P. (2008). Differential effects of endurance and resistance training on central fatigue. *Journal of Sports Sciences, 26*(9), 941-951. doi:10.1080/02640410701885439

Yamamoto, L. M., Lopez, R. M., Klau, J. F., Casa, D. J., Kraemer, W. J., & Maresh, C. M. (2008). The effects of resistance training on endurance distance running performance among highly trained runners: A systematic review. *Journal of Strength and Conditioning Research, 22*(6), 2036-2044.

Zamparo. P., Minetti. A. E., & di Prampero P. E. (2002). Interplay among the changes of muscle strength, cross-sectional area and maximal explosive power: Theory and facts. *European Journal of Applied Physiology, 88*(3), 193-202. doi:10.1007/s00421-002-0691-4

Zupan, M. F., & Scott Petosa, P. (1995). Aerobic and resistance cross-training for peak triathlon performance. *Strength And Conditioning Journal*, *17*(5), 7. doi:10.1519/1073-6840(1995)0172.3.co;2

VITA

DAVID JOHN FISH

Education:	M.S. Sport Science and Coach Education
	East Tennessee State University, Johnson City, TN, 2021
	B.A. Physical Education, Sport, and Fitness Instruction
	Carthage College, Kenosha, WI, 2018
	Downers Grove South High School, Downers Grove, IL
Professional Experience:	Sport Scientist and Strength & Conditioning Coach
	East Tennessee State University 2019-2021
	Assistant Cross Country and Track & Field Coach
	Downers Grove South High School, 2018-2019
Professional Conferences Attended:	ETSU Coaches and Sport Science College, December 2019