8-2017

Outcomes of an Integrated Approach to Speed and Strength Training with an Elite-Level Sprinter

Eric D. Magrum
East Tennessee State University

Outcomes of an Integrated Approach to Speed and Strength Training with an Elite-Level Sprinter

---

A thesis

presented to

the faculty of the Department of Exercise and Sport Sciences

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Master of Science in Sport Science and Coach Education

---

by

Eric D. Magrum

August 2017

Brad DeWeese, EdD., Chair

Kimitake Sato, PhD

Michael H. Stone, PhD

Keywords: Speed, Short to Long Approach, Seamless Sequential Integration

ABSTRACT

Outcomes of an Integrated Approach to Speed and Strength Training with an Elite-Level Sprinter

by

Eric D. Magrum

The purpose of this study was to observe changes in sprint velocity, ground contact time, and peak force demonstrated by a competitive sprinter following an integrated approach to speed development and strength training. As part of an ongoing monitoring procedure the participant completed 20m sprint testing through an optical measurement system and isometric-strength testing before and after each phase of training. Sprint velocity, ground contact time and peak force were analysed using Tau-U, smallest worthwhile and percent change statistics. Results indicate sprinting velocity statistically improved while changes in peak force were practically significant and ground contact time remained trivial throughout the investigation. Results lead investigators to suggest the implementation of a periodized approach merging technical skill and the development of physical abilities. The integrated approach provided a transfer of training effect and may have been the primary source of sprint enrichment.

DEDICATION

This thesis is dedicated to my parents Dan and Laura Magrum, as well as, my brother David Magrum for the best support, guidance and mentorship a son or brother could ask for. Thank you for demonstrating and teaching what it means to carry yourself with the highest integrity. Thank you for providing a breathing example of Grandpa's "Plan your work and work your plan." You have set an exceptional example of what it means to work hard and provide for your family.

ACKNOWLEDGEMENTS

Dr. Michael Stone for your mentorship, insatiable thirst for knowledge, your guidance and advice, and most importantly your service to the many thousands of students, coaches and athletes. Coach Meg Stone for being a Mom to everyone in the department, your mentorship and guidance, your genuine interest in helping others, and your endless pursuit of sporting excellence. Dr. Brad DeWeese for allowing me to follow you around and ask you loads of questions, your mentorship and guidance, and teaching me how to keep the big picture in mind. Dr. Kimi Sato for being an incredible resource for students to go to for many different things and for laughing with me about my awkwardly worded manuscript. Garett Bingham for aiding me in my pursuit of coaching excellence and helping me collect all the data that went into this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Coaches and practitioners around the world seek to gain insights on how to strategize, structure, and devise training programs to enhance sprint speed. Sprinting is arguably the most sought after ability in sport. (Bellon, 2016; Morin, Edoudard, & Samozino, 2011; Nagahara, 2014; Rumpf, 2014). Sprinting can be defined as an un-paced bi-pedal cyclical movement, executed at maximal intensity, and commonly lasting 15 seconds or less. (Ross, Leveritt, & Riek, 2001). Despite the time constraint within this strict definition, the maximal intensity associated with longer events like the 200 and 400 m races solidify their classification as sprint events. Furthermore, texts tend to label the 60 second mark as the threshold for an even split between aerobic and anaerobic contributions to maximal sustained efforts (Stone, Sands, & Stone, 2007). Interestingly enough, evidence leads investigators to believe sprinting speed in humans is largely independent of aerobic contributions under 60 seconds (Weyand et al., 1999). This would create a situation where sprinting activities completed under 60 seconds should be considered sprinting events.

In direct pursuits of speed, which determine the winner as the athlete covering a respective distance in the shortest amount of time, it is evident that sprinting ability is strongly related to an athletes maximal achievable running velocity. Although the athlete who attains the highest sprint velocity does not always attain the highest sprint performance (Bruggeman & Glad, 1990; Mac'kala, 2007; Mann, 2013; Volkov & Lapin, 1979). The author will differentiate sprint speed/performance from maximal velocity, as running speed/performance references a best time over a defined distance and maximal velocity refers to the highest instantaneous velocity an athlete achieves. Attaining this maximal velocity is heavily dependent upon many factors including: ability to produce large amounts of mass specific force (Delecluse, 1997; Seitz, Reyes, Tran, Villarreal, & Haff, 2014; Weyand, 2000), ability to produce force rapidly (Clark & Weyand, 2014), ability to control movement at high velocities (Missitzi, Geladas, & Klissouras, 2004), inter-muscular coordination (Coh, Zvan, Velickovska, Zivkovic, & Gontarev, 2016), technical ability (Morin et al., 2011; Rabita et al., 2015), and most notably, genetics (Eynon et al., 2013; Lucia, Moran, Zihong, & Ruiz, 2010; MacArthur & North, 2004; Scott et al., 2009; Wang et al., 2013).

In the aforementioned direct pursuits of speed, the individual athlete's ability to positively change velocity or accelerate, has been designated a seminal factor on maximal sprinting speed and accordingly overall sprinting performance (Johnson & Buckley, 2001; Mann, 2013; Maulder, Bradshaw, & Keogh, 2008; Sleivert & Taingahue, 2004; Tellez & Doolittle, 1984; Yu et al., 2015). Dictated by the event itself, athletes should achieve the highest horizontal velocity possible in the smallest timeframe. Further, the ability to produce force and velocity then become foundational pieces from which an athlete's ability to accelerate begin.

With the objective of enriching sprint performance it becomes logical to investigate elite-level athletes displaying superior physical aptitudes (Coh & Tamazin, 2006; Rabita et al., 2015; Slawinski et al., 2010). Elite-level subjects are the standard to which others strive. Investigators should use the information gathered from elite athletes to enhance training in a manner, which may allow aspiring athletes to progress toward an elite-level or a higher relative level.

While considering the significance of subjects and their physical abilities, it is vital to grasp the technical demands of sprinting and appreciate sprinting as not solely a physical capacity but as a fundamental skill based on coordination and precision (Debaere, Jonkers, &

Delecluse, 2013; Morin et al., 2011; Rabita et al., 2015). The technical essence of sprinting encompasses many facets including force application characteristics, biomechanical concerns, and motor learning aspects (Francis, 1992; Mero, Komi, & Gregor, 1992; Morin et al. 2011). There is no doubt technical aspects in sprinting performance serve a crucial role. Athletes' technical abilities allow for the modulation of their genetically bestowed and developed physical abilities. Therefore, a coach who outlines a training plan elevating the physiological state of the athlete, serves to deliver greater physical abilities with which the athlete can regulate technical prowess.

The interplay of technical and physical abilities described above affords practitioners many different means to improve sprinting ability. In a recent review Rumpf, Lockie, Cronin and Jalilvand (2016) demonstrated a variety of training stimuli including traditional sprint training, resisted sprint training, plyometric training, and resistance training or a combination of these training means, whether directly or indirectly, can reinforce sprinting performance. Many of these strategies have been used effectively to augment sprinting speed in an array of athletes, however, it has not been well-documented how a coach might merge these entities into a unified approach with elite-level sprinters.

Currently, a paucity of literature exists on how elite-level performers merge training disciplines into a uniform strategy with the ultimate goal of of advancing sprinting speed (Bolger, Lyons, Harrison, & Kenny, 2015). Therefore, the primary purpose of this inquiry is to to observe changes in sprint velocity, ground contact time, and peak force in an elite-level sprinter following an integrated approach to speed development and strength training.

CHAPTER 2

COMPREHENSIVE REVIEW OF THE LITERATURE

Significance of Sprint Speed

Arguably the most captivating ten seconds in sport, the 100m final at the Olympic games all comes down to an ability to sprint very fast. With the sizeable interest, sprinting speed is of vital importance for Track & Field (T&F) athletes of many disciplines and has been the topic for many research endeavors. Some of these investigations contend sprinting speed is the most admired ability in sport and the focus of many training programs (Morin et al., 2011). Many of the inter-disciplines comprising T&F have a distinct goal; to cover a predetermined distance in a shorter timeframe than your opponent. With this very simple goal, it becomes increasingly clear why sprinting speed would be desirable for T&F athletes. Broadening the importance of sprinting speed, a great deal of evidence suggests sprinting speed is not only important in the sport of Track & Field, but is similarly highly advantageous in field/team sport athletes (Bellon et al., 2016). The evidence laid out hereafter should clearly be taken into account for sprinters of all ages, but should also be considered for team sport athletes, as there is a high degree of crossover.

Importance of Investigating Elite Level Subjects

While observing the kinematics and kinetic parameters of maximal velocity sprint running, Deborah Sides (2014) analyzes subject's prominence as many previous research endeavors have investigated sub-maximal running speeds. With the results of the 2016 Olympic 100 m final decided by less than 0.10 seconds, investigators must appreciate how a seemingly meaningless adjustment or enhancement can make the difference between a podium appearance and being omitted from the final. Enhancements will only take place as a result of the observation and investigation of high-level sprinters and their inherent and/or developed physical and technical abilities.

Many authors have previously demonstrated the importance of examining high-level sprinters (Clark & Weyand, 2014; Coh & Tamazin, 2006; Morin et al., 2012; Rabita et al., 2015; Slawinski et al., 2010;). However, literature regarding elite-level sprinting is not readily available, it is logical to assume obtaining information on the integration of complimentary training means in elite sprint-athletes is exceptionally challenging. The information collected, analyzed and returned will aid coaches and athletes in the pursuit of superior sprint performances; however, the study of slower speed running will provide no such benefit.

Physics of Sprinting

In order to better understand and comprehend sprinting performance the author will outline general knowledge of natural sprinting motion applied while observing and attempting to enhance sprinting. Hereafter this will be referred to as the physics of sprinting. This will give the reader a better understanding of the way in which sprinting is viewed by the author, and will lay the foundation for the succeeding sections.

Isaac Newton produced three laws of motion. The first states every object remains in its current state of motion (rest or motion) unless acted upon by an external force. The second is derived mathematically as force= mass x acceleration. The last law states for every action there is an equal and opposite reaction. These laws will aid coaches and investigators in the study of sprinting. Along with these laws there are certainties when it comes to the physics of sprinting. The first of these certainties is that gravity is unalterable and sprinters must produce enough vertical force, in relation to the ground, to refrain from falling (Mann, 2013). The second certainty is the fact that a sprinter's body mass remains relatively unchanged throughout the duration of a sprint.

Newton's laws of motion and two accepted beliefs above give the practitioner guidance as to what then is important for sprinting performance. Applying the second law of motion to sprinting, assuming a sprinter's mass remains constant; therefore, the force a sprinter produces is directly proportional to the athlete's ability to accelerate. If we recall, the ability to produce force is a physical ability termed strength (Stone et al., 2006). Force is a vector quantity comprised of both a magnitude and direction of application. In addition to a magnitude of application from 0-100% and direction of application, the athlete also applies force at a rate or degree of speed (Stone et al., 2003). The aforementioned magnitude, direction and rate of force production are the physical abilities underscoring an athlete's capacity to overcome gravity and begin to explain the qualities practitioners may focus on for further improvements.

Magnitude of Force Application

Numerous investigations have discussed the importance of strength or magnitude of force on athletic performance (Cronin & Hansen, 2005; De Villarreal, Requena, Izquierdo, & Gonzalez-Badillo, 2013; Penailillo, Espildora, Jannas-Vela, Mujika, & Zbinden-Foneca, 2016; Seitz et al., 2014; Suchomel, Comfort, & Stone, 2015) and sprinting performance specifically (Bolger et al., 2015; Bret, Rahmani, Dufour, Messonier, & Lacour, 2002; Delecluse, 1997; Moir, Sanders, Button, & Glaister, 2007; Young, McLean, & Ardagna, 1995). Further, there is evidence to suggest magnitude of force application separates performance level among sprinters (Ae, Ito, & Suzuki, 1992; Slawinski et al., 2015).

Slawinski et al. (2015) highlighted anthropometric dissimilarities between women and men postulating a resultant inferior capability to produce large forward acceleration due to these distinctions. Inferior ability to produce forward acceleration leading to shorter acceleration phases was shown to have detrimental effects on maximal velocity and ability to resist speed decay. These findings highlight the differences in gender but should also be considered when examining the differences within genders. There is little question the ability to produce force underpins and is a pre-requisite for human locomotion and sporting performance.

Direction of Force Application

Hunter, Marshall, and McNair (2005) illuminate three external forces acting on a sprinter's center of mass while sprinting. The three external forces acting on it are: wind resistance, ground reaction force (GRF), and gravity being chief among them. While gravity is constant and unalterable and wind presents differing characteristics in every situation, the sprinter is only left with the ability to alter ground reaction forces. This detail directs coaches and investigators to focus on the forces applied to the ground, the timeframe available to produce force, and in accordance with Newton's third law, the direction in which they are applied.

Ralph Mann provides a theoretical framework to view sprinting and alludes to a force-reserve concept vital to enhancing sprinting performance (2013). Conceptually, this rationale indicates that vertical GRF's required in the sprint are constant and must be met in order for the sprinter to stay in sprinting position, therefore, by increasing the amount of total force applied, the athlete may allocate a greater absolute (newtons) and greater relative amount (%) of force in the horizontal direction, resulting in greater horizontal velocity. Dr. Mann looks to harmonize the vertical and horizontal force components in an applied approach.

In applauding fashion, Clark and Weyand (2015) highlight the importance of a study by Rabita and colleagues (2015) as the first endeavor to acquire ground reaction force data from multiple-sequential steps and do so with high-level subjects, expanding the literature on elite level acceleration characteristics. Rabita et al. (2015) suggest the effectiveness of force application in the horizontal direction is more essential to improve overall sprint performance than very high levels of resultant GRF, which accounted for the difference between highly trained sprinters.

In response, Clark and Weyand call attention to GRF data in relation to body mass for the elite participants in the Rabita et al. (2015) investigation (+20%), which allowed them to exit the blocks with greater velocity (+ 0.44 m/s) compared to sub-elite counterparts. This difference accounted for a great portion of the between group velocities for the entire 40m. This suggests integrated approaches should be installed which serve to optimize mechanics, mass-specific force production and force application as each of these is inter-related and occur as a result of forces produced during each stance phase. Additionally, Clark and Weyand encourage investigators and practitioners to observe forces as integrated components, as athletes and their respective limbs have no recollection of direction. As such, athletes merely push in accordance with alignment and position of the limb and its musculature, irrespective of direction.

The issue of vertical compared to horizontal, sometimes referred to as anteroposterior ground reaction forces has been of particular interest in the past few years. There have been several studies backing both points of view and labeling the other as inferior in its importance. As it pertains to the athlete and the athlete's body, it matters not. The true matter of importance coaches and investigators should focus on comes from structuring training in a manner which teaches the athlete to achieve body positions allowing for the proper orientation of force application to displace the body's center of mass.

Rate of Force Production

Power outputs are perhaps the most important physical characteristics determining sporting success (Stone, Moir, Glaister, & Sanders, 2002). As such, there has been additional investigation into the interconnection between power outputs and the rate at which force is produced (Taber, Bellon, Abbott, & Bingham, 2016). On a conceptual basis, the rate at which force is produced underscores power outputs and may be just as, if not more, important than power outputs determining sporting success (Taber et al., 2016).

From the conceptual framework laid above, the rate at which force is produced underlies the ability to move very fast and can determine sporting success in sprinting. While observing starting block performance of elite and sub-elite level sprinters Slawinski et al. (2010) found RFD to be significantly greater in the elite level sprinters. Clark and Weyand, (2014) highlight the ability of top level sprinters to produce higher forces in the first half of an already very brief stance phase when compared to lower level sprinters at top speed. Thus it can be concluded that RFD is highly important for sprinting success.

Understanding the inter-dependence between and among the ability to produce force (strength), the rate at which force is developed (RFD), and the direction which force is applied is crucial. The physical capacity to produce force underscores the ability to produce high rates of force development, allowing athletes to displace body segments, position limbs, and display desirable mechanics permitting enhanced force application and greater horizontal displacement of the center of mass.

Technical Aspects of Sprinting

Skill can be considered the manner of performing a technique of a physical exercise (Bompa & Haff, 2009). Many sporting events have a technical model or standard which is accepted as being perfect, or as close as possible to perfect, and represents the accepted model of performance (Caine & Broekhoff, 1987). Skill level is the degree to which technique is achieved. The more biomechanically sound the skill level is, the more efficient or economical the athlete will be. In order to successfully execute sporting skill, specific motor components composing the sport technique must be learned. Coker (2013) defines a motor skill as an act or task meeting four criteria: 1) it is performed in order to achieve some objective 2) body and/or limb movements are required 3) movements are voluntary, and 4) developed as a result of practice or experience and must be learned. Learning can then be established as a critical element of sport and is defined as a relatively permanent change in a person's capability to execute a motor skill as a result of practice or experience (Coker, 2013). Therefore, a coach is more accurately a teacher of sporting skills, and athletes' learning depends on the series of experiences a coach constructs and the quality with which instruction is given.

Furthermore, athletes' underlying physical abilities dictate, to a large degree, the extent to which learners can potentially develop proficiency in particular motor components (Bompa & Haff, 2009; Coker, 2013; Young, 2009). Understanding the interdependence of technical and physical capacities will aid practitioners in their ability to devise training plans to augment technical prowess (Young, 2009). Dr. Michael H. Stone (2015) provides additional insight into the interdependent nature of physical abilities, motor control, technique and skill during graduate coursework. Motor control and strength are integrated functions of the same construct; technique results from applying force in appropriate directions, magnitudes and sequences. Skill is the way movement is optimally performed in accordance with the technical model created for the sport; how well an athlete performs this technique is the skill level.

Understanding the kinetic parameters generating performance and the biological systems that govern these performances establishes a base level of knowledge deemed helpful for understanding the succeeding sections.

Phases of Sprinting Performance

Within the sport of Track and Field (T&F) sprinting events are decided by very small margins. To chase the limits of human locomotion, coaches and investigators must inspect all facets of the sprint event. The inspection process begins with block clearance and is comprised of the time it takes for the athlete to exit the blocks and complete the first two steps of the race (Mann, 2013). Examination will evolve into the acceleration phase and ultimately graduate towards maximal velocity sprinting and deceleration from maximal velocity.

Sprint Start

Many previous studies have detailed the importance of the sprint start citing position of limbs, angles of joints, force production, rate of force production, orientation of force application, angular velocities, horizontal power, and horizontal velocity as measures of sprint starting success (Brazil et al., 2015; Harland & Steele, 1997; Maulder et al., 2006; Maulder, Bradshaw, & Keogh, 2008; Mero, Luhtanen, & Komi, 1983; Mero et al., 1992; Milanese, Bertucco, & Zancanaro, 2014; Rabita et al., 2015; Salo, Gayen, Patterson, & Wilson, 2016; Slawinski et al., 2010; Tellez & Doolittle, 1984). Many of the aforementioned characteristics are kinematic concerns and are a result of kinetic characteristics displayed by the athlete. Due to this fact, the author will primarily focus on the kinetic characteristics underpinning these kinematic concerns.

Set Position

Sprints coach Tom Tellez, the coach of 10-time Olympic medalist Carl Lewis and colleague Dorothy Doolittle (1984) breakdown a 100m dash into component parts and quantify their respective contributions. The contribution of the block portion of the race is said to be 5% but also serves to bolster the acceleration phase, estimated to contribute 64% of a 10 second 100m sprint. A critical element of starting performance is the set position a sprinter achieves prior to the sound of the gun, as this situates the athlete in the best position for rapid force production and to displace the center of mass horizontally. Coinciding with findings from Kugler and Janshen (2010) observing physical education students performing submaximal and maximal accelerations, concluded higher accelerations were generated by orienting forces in a lower but more forward manner. Faster subjects displayed a more posterior foot placement paired with greater forward leans resulting in greater propulsive forces. This creates a situation where positioning and placement of body segments dictates functional outcomes and is of upmost importance.

Detailing the importance of a good start on overall performance, the current literature has solidified the start and set position as critical elements for sprinting success. (Coh et al., 1998; Debaere et al., 2013; Milanese et al., 2014). Tellez and Doolittle (1984) detail block spacing, lower limb angles in the blocks, which limb to place forward, and hand placement in the blocks. In contrast, Salo et al. (2016) observed university level athletes and advise coaches to allow athletes to choose block settings they are comfortable with rather than placing them into blocks based on strength of legs. Further contrasting Tellez and Doolittle who advocate a 90 degree front knee angle and 135 degree rear knee angle, Milanese et al. (2014) who used university level athletes to conclude a 90 degree rear knee angle allows for greater horizontal velocity while leaving the blocks, but requires significantly greater timeframes. This may be problematic as the increased time needed to create greater horizontal velocity may be counterintuitive. It seems coaches should aim to optimize both force generated and subsequent velocity with the time taken to do so.

None the less, sprint coaches should strive to set up athletes blocks in a manner by which they display 90-100 degree front knee angles and 120-140 degree rear knee angles (Harland & Steele, 1997). This should be done early in the training year to familiarize athletes with correct positioning, serving to allow them to feel comfortable and familiar with good positions during the crux of competition.

Physical Abilities and the Sprint Start

During the sprint start from blocks, it becomes especially important to develop force as fast as possible (Mero et al., 1983). Maulder et al. (2006) examined male track athletes sprinting from blocks and concluded the ability to generate power during static and countermovement jumps were good indicators of 10m sprinting performance. In a more direct manner Slawinski et al. (2010) used motion analysis capture system to calculate rate of force development and impulse during the pushing phase on the block of elite level sprinters. Findings presented elite level sprinters separated themselves by placing their center of mass closer to the finish line, displaying greater explosive strength, and having better arm coordination. These results clarify the foundational role served by an athlete's physical abilities and how technical prowess and physical abilities are highly integrated.

Creating horizontal velocity in large amounts is the objective of the sprint start (Mann, 2013). Developing necessary supporting forces (vertical) allows for all other force production to be allocated horizontally producing the most horizontal velocity possible. This goal is accomplished with optimal block set up, correct starting positions, mechanical proficiency, and the physical abilities of the athlete in the form of strength and rate of force production. Tellez and Doolittle (1984) have considered block set up, set position, and block clearance to be indispensably important to the sprint start and succeeding transition and acceleration phases of the race. Starting and acceleration abilities have been found to directly generate results in the 60m and 100m races (Slawinski et al., 2010). Therefore, the start serves as the cornerstone of these competitive sprint races, and has the capability to situate athletes to a position where sprinting brilliance is attained.

Acceleration

Understanding the importance of attaining the highest horizontal velocity possible, the athlete is tasked with pursuing the maximal sprinting velocity he or she can achieve. In order to attain maximal velocity, the athlete should strive to accelerate for the longest distance in the shortest possible timeframe (Tellez & Doolittle, 1984). As the athlete accelerates for a longer period of time, the inevitable deterioration of sprinting velocity is prolonged to later point in the race, which may allow them to maintain a higher average velocity throughout the race.

The importance of acceleration, maximal velocity and speed decay are exemplified in a paper by Ae et al. (1992) displaying the 10 meter intervals of finalists at the 1991 Tokyo track championship. The information shown here illustrates the ability of higher level performers to not only attain superior sprint velocities, but also decelerate less compared with other lower performing finalists. With closer examination of the data from this endeavor the eventual winner (Carl Lewis) is behind eventual 3rd and 4th place finishers until at least the 70m mark and quite possibly just before 80m. Finishing, Lewis was unable to overtake the eventual second place finisher until the 90m mark.

The potential underlying explanations for this manifestation may be a prolonged acceleration phase. The prolonged nature of this phase may have given Lewis an extended timeframe to produce force, resulting in greater terminal velocities and momentum. In agreement with previous literature van Ingen Schenau and colleagues (1994) establish maximal sprinting velocity depends on and is dictated by the preceding acceleration phase. Therefore, the acceleration phase forms the essential linkage between the sprint start and maximal velocity sprinting.

The acceleration phase has been previously subdivided by Debaere and colleagues (2013) into an initial acceleration (IA) (0-10m) and a transition phase (TP) (10-30m). The IA is heavily dependent upon the sprint start and the success of the TP is dictated by and affective IA. The IA is characterized by a forward lean of the trunk and powerful extension of the lower limbs. The forward lean of the trunk allows the athlete to exert force down and back into the ground, as foot-ground contact is made in front of the sprinters center of mass and can be viewed as part of the technical element of sprinting. Important to note, high-level sprinters do not drive through full knee extension in this phase, as a quicker reposition of the limb outweighs the benefits of full extension (Mann, 2013). Sprinters displaying proficient accelerative abilities will demonstrate movements predominantly in the front of the body, actively and aggressively attack the ground, and have large amplitudes of arm movements.

Morin et al. (2011) found the way in which force is applied to the ground to be a determining factor in 100m sprint performance. In accordance with Newton's third law of motion, Morin et al. (2011) highlight the importance of orienting forces horizontally and label the vertical portion of force production ineffective but required in producing forward acceleration. In a recent influential investigation, Rabita et al. (2015) examine elite sprinters and their sub-elite counterparts in a virtual 40m acceleration from blocks and agree the effectiveness of force application is of vital importance and can separate elite from sub-elite level sprinters.

Supporting the ability of sprinters to orient their forces down and back, Nagahara, Mizutani and Matsuo (2016) examined step-to-step ground reaction forces from a well-trained sprinter in a simulated 100m race. Fifty-four force platforms were laid down under a track surface and measured the ground reaction forces from the block start to the 50.5m point. Findings report vertical and horizontal ground reaction forces increased and decreased until approximately the 17^{th} step. Results highlight the transition of the sprinter's body position around the fifth step of the simulated sprint race characterized by the increase in propulsive impulse, stabilization of step frequency and suspension of decreasing ground contact times.

The IA from blocks, the TP is characterized by a progressive transition from the forward trunk angles seen in the IA to an upright running postures seen in maximal velocity sprinting. The objectives of the TP are to build upon the velocity and momentum generated during the start and IA as well as position the sprinter in advantageous postures. Although not well studied, the transition phase has the ability to set-up subsequent phases within the sprint race.

Hunter et al. (2005) examine sprint acceleration kinematics and ground reaction force data at the 16m mark and found horizontal impulse and sprint velocity to have a strong relationship. Although not entirely indicative, GRF data at the 16m mark was found to be representative of the athlete's ability to apply GRF during previous stance phases. Relative propulsive impulse accounted for 57% of sprint velocity variance, while relative braking impulse accounting for only 7%. Hunter et al. conclude the most favorable magnitude of relative vertical impulse is one creating brief flight times allowing the reposition of limbs and all other strength reserves be directed horizontally.

More recently, Yu et al. (2016) provide some insights from their investigation comparing the transition phase to the maximal velocity phase in twenty young male sprinters. Findings included a decreased braking duration and increased propulsive duration during TP compared to maximal velocity. Interestingly, horizontal braking forces were significantly different but horizontal propulsive forces were similar during the two sprint phases, potentially indicating greater acceleration is caused by lower horizontal braking as opposed to greater horizontal propulsive phases. Techniques to decrease braking may be beneficial to the competitive sprinter.

Performing an effective transition allows the fusion of the initial acceleration and the maximal velocity phase and dictates how the sprinter will enter this next phase. Maximal velocity, which has been considered significant to sprinting performance, is dependent on a refined ability to accelerate and therefore should be a point of emphasis while training sprint athletes as well as field and court sport athletes.

Maximal Velocity

Perhaps the most investigated aspect of sprinting, the maximal velocity phase, contains athletes' top end speed and has been strongly correlated with sprinting performance (Bruggeman & Glad, 1990; Mackala, 2007; Volkov & Lapin, 1979). By gradually increasing body postures and generating copious amounts of momentum, proceeding phases serve to position the athlete optimally for maximal speed. From the gradual progression body segments, maximal velocity sprinting is characterized by upright postures whereas the sprinter is in a "tall stacked" position with regard to the shoulders and hips. Sprinters should display leg movements primarily in the front of the body and contact the ground slightly in front of the center of mass (Mann, 2013). These mechanics allow for optimal force production as well as economical translation down the track. Importantly, without the proficient navigation of previous phases, it is difficult to apply forces and achieve positions necessary for high-level performance. Thus, the maximal velocity phase of sprinting will leave something to be desired.

Paramount to understanding the maximal velocity phase of sprinting, a research group directed by Dr. Peter Weyand has provided practitioners with valuable information, which serves to aid both athlete and coach through the training process. The first of Weyand and Colleagues findings was in 2000 concluding faster top speeds are attained with greater ground reaction forces rather than a quicker repositioning of the limbs. In accordance with findings in 2000, Weyand and colleagues (2006) concluded sprint performance is dictated by the time available to produce force. In 2010, Weyand et al. examined forward and backward running along with hopping and concluded maximal volitional forces cannot be applied within the stance timeframes, as such the large mass-specific forces necessary for high-level sprinting must be developed quicker to improve performance.

While examining elite level sprinters compared to sub-elite sprinters and collegiate athletes, Clark and Weyand (2014) discovered elite level sprinters display an asymmetrical force time curve opposing the spring mass model of sprinting, which postulates the first half of sprint stance is used to store elastic energy via eccentric contraction of the muscle-tendon unit and released during the second half (Dickinson et al., 2000). This finding further highlighted the importance of sprinters' ability to produce high levels of mass specific force in brief time periods.

Sprinters' ability to produce asymmetrical force time curves was not exclusive to higher running speeds. Whether this ability is indicative of elite level sprinters genetic ability to produce force, trained ability to produce force, or technical proficiency over many years of training, remains to be seen. It is likely elite-level sprinters' possess genetic traits lesser sprinters lack, as well as demonstrate greater technical prowess.

Moreover, Clark and Weyand (2014) found the ability to produce more force in the first half of the stance phase separated level of performance. Buechner et al. (2015) examined collegiate athletes accustomed to short duration sprinting at maximal velocity on a high-speed instrumented treadmill. Examination lasted no less than six sessions including one treadmill acclimation day, pre-test, gait intervention/drills/sprints and post test. Sprinting trials on gait intervention days were completed by subjects at 90% while receiving cues. In addition to cues during sprinting, three sprint drills were performed before sprint trials to maximize ground-foot collision. The three drills used included: double quick leg hop, A-skip with a pause, and single leg rapid high knee. Results of the study suggest alterations to gait mechanics were the causal factor in creating a 6.7% increase in top speed. This increase in speed was done without an increase in average ground reaction force following intervention, however, there was a slight increase in vertical forces applied during the first half of foot-ground contact. Findings lead the authors to believe in accordance with Clark and Weyand (2014) the intervention emphasizing the first half of ground contact may have enabled subjects to apply greater forces in the first half of the stance phase, leading to faster sprint velocities at maximal velocity.

With greater technical proficiency and enhancements in training humans are able to apply larger and larger forces to the ground in seemingly smaller timeframes. Is there then a limit to human's ability to sprint at maximal velocity? Miller, Umberger, and Caldwell (2012) use 2-D modeling to determine the function of specific tissues of the body while sprinting maximally. Findings indicate the most important contractile property of muscle regarding the limits to maximum velocity is the force-velocity relationship. Zatsiorsky and Kraemer (2006) remind us the force velocity relationship states force and velocity of contraction are inversely related, as one increases, the other decreases proportionally.

After a sprinter has attained his maximal velocity, it is of primary importance that the sprinter delay a decrement in speed for as long as humanly possible. Evidence of this exists in Ae et al. (1992) in addition, it is shown top level performers not only achieve a higher velocity but also tend to minimize (to a greater degree) deceleration from maximal velocity compared to inferior performers.

In an analysis of the worlds fastest man, Usain Bolt's best three sprint performances of 9.58, 9.63, and 9.69 s in the 100m were compared. Upon investigation, investigators and practitioners can appreciate the magnitude of this data and its relevance for future performance enhancements. As such, it is not Bolt's ability to attain a higher maximal velocity, which separates the three races; it is the initial acceleration and transition that make the difference. In fact, Bolt maintained a higher maximal velocity for a longer period of time in his London Olympics performance of 9.63 s compared to his world record 9.58 s in the Berlin performance.

Demonstrating the importance of a holistic approach in sprinting, one cannot focus solely on one phase of the sprint but must configure a way in which all phases of the sprint are learned in sequential order as to reinforce sprint specific physical literacy as well as technical proficiency. Training with the aim of enhancing the ability to produce force quickly (RFD) and demonstrating higher levels of technical proficiency are likely beneficial and should be the foundation of training programs.

Physiological Underpinnings of Sprinting Performance

In the last 8 Olympics the difference between standing atop the podium with a gold medal (1^{st}) and being omitted from the podium, (4^{th}) was decided by less than 1.5% (DeWeese et al., 2015a). Moreover, the difference between first and fifth place in a sprint can be hundredths of a second, therefore seemingly trivial disruptions in training may have large consequences (McCann, 2008). With this in mind, a coach's understanding of how training may affect performance is of high importance, as previous studies have found tapering strategies to elicit performance improvements between 3 and 6% (Bazyler, 2016; Mujika & Padilla, 2003). Although these studies were conducted with throwing and distance athletes, this evidence highlights the importance of understanding training theory and the biological processes governing performance and suggest certain strategies could potentially take an athlete from merely being in the final to winning the gold medal.

As detailed in earlier sections, the importance of strength, rate of force development, and power are important for high levels of sprinting success. Further, it should be understood these physical abilities are resultant of the athlete's physiology and may only be realized when the athlete's physiology is in an optimal state. Therefore, training exposures affect the physiology of the athlete, which serve as the basis of performance. In order to alter physiology, training must be planned, encompass intelligent design, and adhere to sound principles allowing for injury prevention and performance improvement. Understanding the underlying mechanisms along with biological processes and their interaction with performance are vital for eliciting desired adaptations at advantageous time points.

Physiological Mechanisms

The basic function of muscle is to generate force; as a result, muscular contraction is the source of human movement (Stone, Stone, & Sands, 2007). The interaction or cross-bridging of contractile elements actin and myosin have been elucidated previously (Huxley, 1958; Huxley & Hanson, 1954; Huxley & Niedergerke, 1954) and form the foundation for muscular contraction. A well-known contractile phenomenon detailing the trade off between speed of contraction and force of contraction is the force-velocity relationship. Simply enough, as sarcomeres begin to move at faster speeds, it is increasingly difficult for cross-bridges to attach, resulting in fewer cross-bridges. Fewer cross bridges lead to lower force outputs as force applied depends on the number of attached cross-bridges (Cormie, McGuigan, & Newton, 2011). Thus, the relationship between speed of contraction and number of cross-bridges formed dictates force generation capabilities (Stone et al., 2007) and consequently human locomotion.

Detailed above, the force-velocity relationship has limiting affects on maximal sprinting speed (Miller et al., 2012). Representing the fastest possible cross-bridge cycling rate of muscle, Vmax correlates well with the maximum dissociation rate by Adenosine Triphosphate (ATP). Due to the inability to form a cross-bridge while intact with another protein, the biological processes required for disassociation and re-attachment, termed enzyme kinetics, serve to place a governor on contraction velocity (Barany, 1967; Nyitrai et al., 2006; Siemankowski, Wiseman, & White, 1985;). Although the fixed rate of attachment and detachment of cross-bridges provides challenges physiologically, increasing force capabilities leading to increases in speed may be optimized with other strategies.

Regulating rapid force production, muscle fiber type partially determines sprinting success (Thorstensson, Grimby, & Karisson, 1976; Tihanyi, Apor, & Fekete, 1982). Seven human muscle fiber types have been previously identified and lie on a continuum (I, IC, IIC, IIAC, IIA, IIAB, IIB) characterized by speed of contraction with type I and type IIB representing the slowest and fastest renditions (Scott, Stevens, & Binder-Macleod, 2001). While training can serve to alter fiber type and size (Anderson & Aagaard, 2010), peak power outputs have been shown to be greater in muscle groups with type II fibers compared to type I fibers (Thorstensson et al., 1976; Tihanyi et al., 1982). Moreover, it would be advantageous for sprint athletes to increase the amount and mass of type II muscular fibers whilst decreasing type I fibers.

In 1976 Costill et al. confirmed previous research findings and theories about the notion of strength and speed athletes possessing greater amounts of type II fibers. Along with this verification, validation of yet another significant finding highlighting the importance of athlete's genotype was corroborated. In a recent investigation from Ball State University Trappe and colleagues (2015) evaluated the skeletal muscle of a current world record holder in the 60m hurdles and former world record holder in the 110m hurdles. With the importance of examining elite level subjects exhausted previously, the notion of evaluating the physiological characteristics of an athlete of this caliber is quite fascinating. Resulting from muscle biopsy, discoveries include a high abundance of type IIx muscle fibers (24%) and a total fast twitch fiber populace of 71%. Power outputs comparing type IIx to IIa were 2-fold greater and 14-fold greater than type I. Expanding Costill and colleagues (1976) declaration of genotype's prominence on athletic success, transcription level for growth and remodeling genes of type IIx fibers were highly responsive to intense exercise. Findings of this nature only further substantiate the heavy implications genes have on athletic performance.

Characteristics of muscle, including fiber type and proportion of various fiber types, are important to understanding the entire physiological profile of muscle. It is important to understand the physiological profile of muscle architectural constructs as well. A seminal concept in understanding muscular physiology is the relationship between cross sectional area (CSA) and maximal force production. This concept will serve as one of the foundational elements from which training plans will be constructed.

Previous investigations have established the amount of force generated by a muscle is directly proportional to the muscles CSA, regardless of fiber type (Bodine et al., 1982; Cormie et al., 2011). As has been noted throughout this piece, power and the ability to produce force quickly is important to sprinting. If power is equal to the force produced multiplied by the velocity (F x V), and we recall velocity of contraction is limited by enzyme kinetics, then power is influenced by CSA and a muscle with higher CSA should produce greater power (Malisoux, Francaux, Nieiens, & Theisen, 2005; Shoepe, Stelzer, Garner, & Widrick, 2003; Widrick, Stelzer, Shoepe, & Garner, 2002). Wessel et al. (2010) present data indicating an inverse relationship between muscle fiber size and oxidative capacity. It seems muscle fiber size and oxidative capacity are in constant turmoil and contest each other, as these characteristics are influenced by different signaling pathways which drive opposing adaptations. With this knowledge, a sprinter should strive to increase mass specific force production, and although increases in muscular size can yield increases in overall force production and could beneficially effect sprint performance, increased CSA could potentially come at the expense of sprinting performance. Care should be taken to ensure that increased CSA is not indiscriminate and that architectural specificity is preserved and the II:I CSA ratio is enhanced. Importantly, heavy strength training and high velocity have been shown to enhance hypertrophy of type II muscle fibers to a greater degree than type I (Cormie et al., 2011). Although, much of this research is completed on relatively untrained individuals with moderate strength levels, stronger more experienced athletes will gain less CSA and take a greater duration to do so (Sale, 1988).

Conceptually, the maximal force exerted by the athlete and the maximal velocity of movement by the athlete represent the two terminal ends of the force-velocity curve. Maximal power output is thought to reside directly between these two polar ends. The physiological mechanisms leading to greater force output are greater CSA and the mechanisms leading to greater contraction velocity are enzymatically limited. Consequently, progressing athletes' muscular power is influenced primarily through heavy strength training as opposed to specific power training (Cormie et al., 2011).

In addition to the above mechanisms, fascicle length and pennation are architectural components of muscle serving to aid primarily in velocity of contraction and force of contraction respectively. The velocity of a muscular contraction has been found to be proportional to its length (Bodine et al., 1982; Edgerton et al., 1986). Since power output is heavily reliant on velocity, it would be advantageous for sprinters to exert higher velocities through longer fascicles. Previous findings support fascicle length as an indicator for sprinting performance in the 100m (Cormie et al., 2011). Comparing and contrasting sprinters and long-distance runners, sprinters have been found to have significantly longer fascicles compared to their long duration, slower velocity counterparts (Cormie et al., 2011). It is not well understood if sprinters possess greater fascicle length due to specific training or genetic endowment (Cormie et al., 2011). Training modalities with the goal of eliciting greater fascicle length have been inconclusive, and require further research to be well understood.

Pennation angle has been correlated with a muscles ability to produce force (Cormie et al., 2011) and therefore is important to power output capabilities. Although an increase in pennation angle is found to have negative effects on maximum contraction velocity, it is theorized the loss in contraction velocity is counteracted by proportionally larger increase in force production leading to greater power (Cormie et al., 2011). Moreover, heavy strength training has been shown to increase pennation angle as well as CSA and force exertion capabilities (Cormie et al., 2011). However, more examination is required to establish how pennation angle adaptations to heavy strength training.

With the current understanding of physiological mechanisms underlying performance, the coach may now be guided through neurological morphologies taking place. These adaptations serve to deliver the signal to the developed muscle at a quicker rate and/or in sequential fashion in order to produce the desired movement, minimizing extraneous movements and forces.

Neurological Mechanisms

The essence of life on earth is movement. In order to move, a person must activate the appropriate muscles through stimulation of motor neurons serving to produce forces required for the desired movement. Therefore, any movement can be viewed as a highly technical, information rich, and precision based conversation between the nervous and muscular systems resulting in force application (Jeffreys & Moody, 2016). As we understand from previous sections, protein cross-bridging is the result of an action potential, and force application is a result of cross-bridging. Ion fluctuations in the membrane of cells create this action potential and occur in response to a stimulus. If large enough, the action potential stimulates an electrical charge or nerve signal that further propagates down the axon of the nerve, via saltatory conduction, towards the intersection of the nerve and muscle, more commonly termed the neuromuscular junction (Stone et al., 2007).

As the nerve impulse reaches the neuromuscular junction, the terminal end of the axon releases neurotransmitters contained in synaptic vesicles, lying within the synaptic bulb or knob. At the instant a sufficient action potential arrives at the synaptic bulb, neurotransmitters are released and traverse the synaptic cleft, binding to receptors at the muscular level and serving to depolarize the muscle and ready the tissue for contraction, force output, and subsequently movement (Kenny, Wilmore, & Costill, 2012). Mentioned briefly above, there are many steps and processes involved. Important to understand, sporting movements are the result of a neurological signal's interaction with the muscular system.

With specific sporting movements studied and found to occur in less than 0.3 seconds (Taber et al., 2016) the required conversation between the muscular and nervous system resulting in sport movements occurs at an even greater rate. Sensory stimuli via the afferent neurons is interpreted and then sent downstream as motor commands to enhance movement via efferent neurons. Therefore, training to enhance the neuromuscular system's prowess should be at the forefront of all training programs. Enhancing neural transmission by one to two milliseconds may seem trivial; however, sprint races can be decided by hundredths or thousands of a second. From a practical standpoint increasing nerve conduction velocity by a millisecond or two could mean the difference between a gold and silver medal.

Nerve conduction velocity (NCV) is the speed at which a nerve impulse travels down to an effector cell or tissue. Although not much research is available detailing NCV and explosive performance, a recent study by Methenitis and colleagues (2016) establish correlations between

NCV of the vastus lateralis and countermovement jump performance. Findings show NCV and RFD are closely linked and of interesting note the correlation between NCV and RFD at 50 milliseconds was lower than at later time periods. The authors postulate non-efficient recruitment of type II muscle fibers in very early portions of explosive performance for this result, as they were not power-trained. The results established a link between NCV and multi-joint explosive performance and also found NCV is more highly correlated to RFD than maximum isometric force.

Serving to hasten the speed of the nerve signal down the axon, two aspects of the neuron determine how quickly the impulse travels: diameter and myelination (Kenny et al., 2012). Myelination is the insulating layer surrounding a nerve fiber (Saladin, 2010) and has been linked to skill acquisition and strength (Kenny et al., 2012). Myelin helps transmit nerve signals relatively long distances in an efficient manner, and the larger the myelin sheath, the greater the speed with which signal propagation occurs (Banich, 2004). While myelination is not a specified target of the training process, it remains a vital component in the speed at which neural signals travel and can produce desirable actions from effector cells.

Neuronal diameter can also serve to quicken nerve impulses towards effector cells. The greater the diameter of the neuron, the greater the surface area, which allows for enhanced NCV when compared with smaller fibers (Saladin, 2010). Commonly understood, the functional properties of motor units, including size, depend on muscular function and activity pattern (Mrowczynski & Lochynski, 2014). This evidence along with other evidence (Ross et al., 2001) postulates that with training, the size of the neuron may be upgraded or degraded with the training modality chosen. Just as observed in bone, Wolff's law (Frost, 1994) may apply to neurophysiology. Implying that training may stimulate remodeling structures to better suit the environment or demands placed on it, more research is needed.

With the foundational elements of the electrical impulses sent from the nervous system to the muscular system detailed above, a description of neural characteristics of more applied mechanisms leading to performance will now be specified including: firing frequency, synchronization, coordination, co-contraction, and co-relaxation.

Firing frequency or rate coding, describes the rate at which neural impulses are transmitted to the muscle from the motor neurons (Cormie et al., 2011). Increasing firing frequency increases the magnitude of force production and has been estimated to increase as much as 15 times (Enoka, 1995). Additionally, firing frequency has also been shown to impact RFD as a result of increasing motor unit recruitment, rate coding, and an increase in doublet discharges attributed to ballistic type training in the tibialis anterior (Van Cutsem, Cuchateau, & Hainaut, 1998). Doublet discharges are rapid bursts of two action potentials instead of one, allowing for ultimately higher force outputs at an increased rate. This may be especially important for sprinters whose speed of contraction is of utmost importance. Although there is support to suggest maximal voluntary contraction is not enhanced with training, most recent studies detailed in by Cormie and colleagues (2011) suggests training does in fact enhance maximal voluntary contraction.

Coordination of motor units is of vital importance as agonist and antagonist musculature contest each other with the flexion or extension of limbs. If an athlete lacks synergy between muscle groups and/or motor units, he will be generating a resistance to his/her own performance. As synchronization can be linked with RFD (Semmler, 2002), the sequential musculature contractions used to produce forces needed to display certain body positions in sprinting are vitally important.

In a recent inquiry, Coh and collaborators (2016) detail the importance of both intra and inter-muscular coordination in elite level sprinters. Coordination, much like synchronization, serves to allow athletes to sprint with great efficiency, allowing for the summation of forces around a joint to displace the center of mass, as opposed to, minimization of forces around a joint due to a lack of coordination. Further, Coh et al. (2016) detail the critical nature of co-activation of agonists and antagonists permitting the lower limbs to function as very stiff springs, allowing for a diminished vertical drop of the hips which has been determined a key parameter of elite level sprinters by Mero et al., (1992).

The above information is a snapshot synopsis of the governing elements of translating synaptic input into a sequence of motor commands, executed by muscle fibers, resulting in movements. It should now be understood there are many mechanisms underlying performance. We have some idea of how training impacts these mechanisms, but much remains to be elucidated. In the following sections, the training used to elicit and enhance these mechanisms will be detailed.

Understanding Physiology Allows for Superior Training Means

The ability to view training as a means to alter physiology and bolster performance from enhancements in technical proficiency stemming from enhanced physicality, will allow the astute coach the capability to deliver an enhanced service to the athletes they oversee. Grasping the various mechanisms driving the physiological adaptations specified above, the coach may now critically assess the merit of training activities as it pertains to the time of year, fitness phase, training foci, and adaptation process. Critically assessing the training plan and process is an important aspect if the coach seeks further improvement. When devising a training plan, obtaining the underlying rationale for training decisions is of paramount importance. Stated differently, the coach should understand the "why" behind all training decisions made and refrain from making decisions based solely on tradition and previously accepted training practices. The following sections will detail the implementation of Seamless Sequential Integration (SSI) and importantly a rationale as to why training decisions are made, although, not all decisions will be elucidated, many examples will be given.

Seamless Sequential Integration

With the goal of maximizing sprinting performances, both maximal strength and power are important attributes; as a result, the need for an integrated strength training program becomes obvious (Bompa & Haff, 2009). Seamless Sequetial Integration (SSI)! Devised and first described in the literature by DeWeese, Sams, & Serrano (2014), SSI is a model of training which blends the tenets of the Conjugate Sequential Sequencing (CSS) in conjunction with a short to long speed development approach. Originally developed for Track & Field athletes and later used with winter sport athletes, SSI allows the development of physiological abilities while serving to hone an athlete's sprinting aptitude. Although many programs have been shown to improve strength and speed (Rumpf, Lockie, Cronin, & Jalilvand, 2016), to date there is a paucity of literature illustrating the integration of strength and sprint training among competitive sprinters (Bolger et al., 2015). SSI has been implemented within a variety of different sports requiring speed, strength and explosiveness. In this endeavor SSI was used to enhance the attributes of an elite level sprinter.

Strength Training Theory & Design

Strength training forms an essential pillar from which SSI was built. The purpose of strength training within the SSI model is to enhance the athlete's physical abilities in such a way to allow superior technical and tactical prowess within the competitive endeavor. Conjugate Sequential Sequencing (CSS) is the manner in which training stimuli are specifically planned to elicit superior adaptations. However, in order to understand the merits of SSI and CSS, it is first necessary to understand the concept of periodization. As Plisk and Stone (2003) state periodization is the logical phasic manipulation of training factors in order to optimize the overall training process. Further definitions include the cyclical nature of training and the inclusion of a comprehensive monitoring system (DeWeese, Sams, & Serrano, 2013). Although often used synonymously, it is important to note the difference between periodization and programming. Periodization deals primarily with timelines and fitness phases and the latter details numerical sets and repetition schemes (Stone et al., 2007).

Specified in other works on periodization, conjugate successive sequencing (Bompa & Haff, 2009; Stone et al., 2007; Verhoshansky, 2006; Verhoshansky & Siff, 2009), long term phase potentiation (Harris et al., 2000; Haff & Nimphius, 2012; Judge, 2007) and block periodization (Issurin 2008, 2010) are conceptually alike. Serving to sidestep confusion for the reader, conjugate successive sequencing will be the primary referenced term. It matters not which term (CSS, Phase Potentiation, Block Periodization) is explained as all are strikingly similar, and more importantly, the mechanisms underlying the foundational premise of the above terms are exactly the same.

Moreover, while explaining conjugate successive sequencing (CSS) Verhoshansky & Siff (2009) describe the use of concentrated workloads, unidirectional loading, and consecutive rather than simultaneous development of abilities. Further, Plisk and Stone (2003) cite the role of the delayed training effect as the basis of this system. Logically termed, delayed training effects are those not seen for a period of time after training is imposed. (Stone et al., 2007). Delayed training effects may modulate responses in future blocks, while suppressing emphasized abilities during high workloads (Bompa & Haff, 2009). Displaying differing rates of decay, physical abilities are heavily based on enzymatic properties (Viru 2001,1995; Plisk & Stone, 2003). As discussed in the sliding filament theory above, these enzymatic properties serve to speed up biological processes and allow for enhanced movement. Therefore, it becomes important to understand the role of how training impacts these enzymes, which regulate adaptation and performance.

Plisk and Stone (2003) discuss the importance of the preparatory period (length, size) in determining the stability of residual training effects and their corresponding enzymes. Sound training residuals, founded in the preparatory period, allow for the maintenance of abilities with minimal loading, permitting emphasis to be assigned elsewhere as well as controlling residual fatigue. Therefore, it is beneficial to have long periods of preparation to maximize the accumulation of training residuals and optimize performance during critical time periods. It would be remiss to underestimate the importance of early portions in the training process.

Comprehending the importance of delayed training effects and enzymatic processes, discussion can now move to more applied tenets of CSS. Essential to the training of elite athletes, concentrated loads (CL) imply a specific attribute is focused on and training volume or intensity of this chosen quality is above normal levels. The foci of a CL may be a physical ability (strength endurance, strength, RFD) or a desired skill (acceleration, maximal velocity, speed endurance). Generating superior adaptations through larger specific disturbances in homeostasis is a central strategy to CSS (Verhoshansky & Siff, 2009). After the completion of a CL, training of that specific quality moving forward is de-emphasized usually from a volume standpoint but is still incorporated to postpone involution as shown in Figure 1 below. Training then advances to another CL with a focus on a different attribute. Employing concentrated strategies has been known to produce long lasting after effects serving to enhance or potentiate subsequent training phases, otherwise known as phase potentiation (DeWeese, Hornsby, Stone, & Stone, 2015b). Phase potentiation serves to build on previous blocks of training allowing superior training adaptations when compared with non-sequenced training periods (Haff & Nimphius, 2012).

Practically, Harris and colleagues (2000) demonstrated this with football athletes while inspecting differences between three weight training protocols: high force, high power, and combination (sequenced) of high force and high power. Findings indicate speed-strength training or a combination of heavy strength and power training proceeded by heavy weight training produce greater results compared to speed or heavy weight training alone. Therefore, it is likely beneficial for athletes and coaches desiring explosive performance to sequence training means from a maximal strength emphasis to an explosive emphasis.

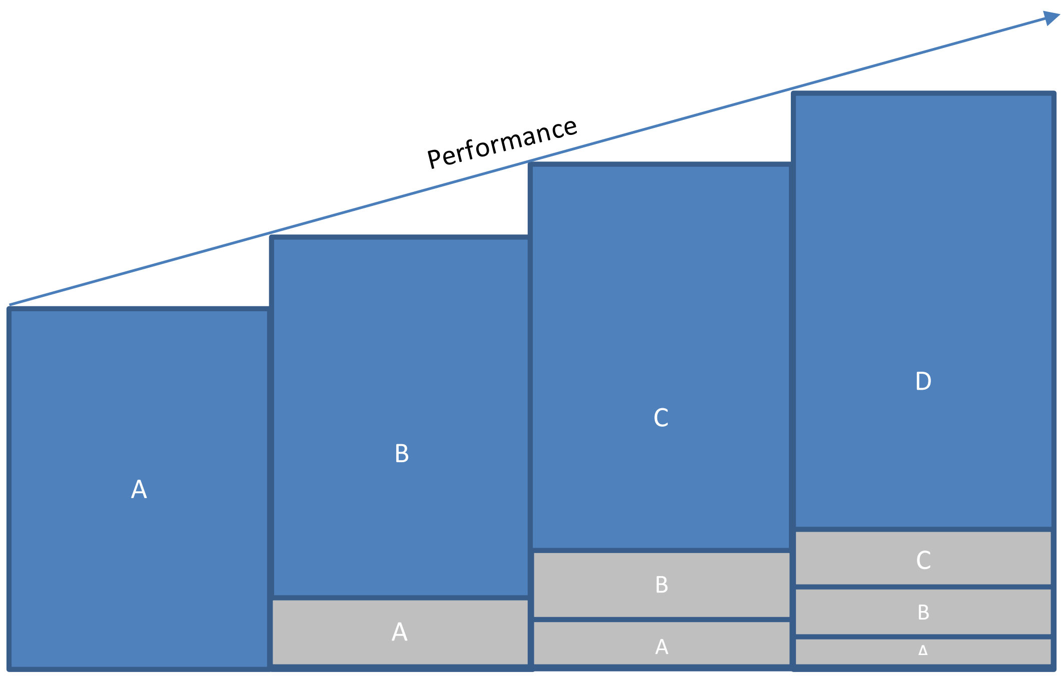

Figure 1. Sequence of Stimuli in Conjugate Successive System. Adapted from Verhoshansky & Siff (2009)

Unidirectional loading provides contrast between the two main systems of organizing training: concurrent system and the conjugate sequential system (Verhoshansky & Siff, 2009). Concurrent systems of training focus on many tasks simultaneously. Verhoshansky and Siff (2009) state the concurrent system does not allow for as great of a specific disturbance of homeostasis, therefore elicits a broadened adaptation. A multivariate approach associated within traditional periodization may promote enhancement and entertainment in low-level athletes. However, high-level athletes require higher levels of stimulation to evoke desired adaptations making multi-focused training approaches inefficient at best (Issurin, 2010). The conjugate sequential system uses unidirectional loading, which implies the focus of training is on one quality. Importantly, unidirectional loading is used optimally only if utilized in conjunction with successive unidirectional loads.

As training graduates from general to specific abilities, development of physical qualities is summated on using the previously enhanced general training emphasis, as a foundation that leads to higher levels of specific enhancement. Important to emphasize the single foci of unidirectional loading does not mean the chosen quality is trained exclusively (Verhoshansky, 2006). The emphasis in the training phase is on a chosen quality and retaining loads are prescribed for maintenance of other qualities (DeWeese et al., 2015b).

Previously used by educators, concentrated and unidirectional loading has been in use for decades. For example, if multiplication is the desired outcome, it is of benefit to the student to learn addition and subtraction processes before progressing to higher levels of mathematical prowess. When developing multiplication skills, addition and subtraction are not forgotten and unused but serve as a secondary and necessary skillset. One might observe the summation of educational skillsets from lower to higher levels of expertise and draw parallels to the development of the physical skillsets in a training environment.

Continuing with the analysis of CSS, the use of specialized mesocycles merely entails the logical and sequential order of training phases, otherwise referred to as ‘blocks’. There are currently three types of mesocycle blocks commonly referred to: accumulation, transformation and realization (Issurin, 2008). Accumulation strives to develop basic abilities and movement techniques. Transformation seeks to develop more specific abilities building from basic abilities established in the previous block. Realization then serves to maximize previously developed abilities into competition specific abilities as to optimize performance.

Taking advantage of residual effects, logical sequencing of concentrated loads can yield heightened performances. Sequential strategies manipulate phases of accumulation followed by restitution phases, which allow for the carrying of amplified physiological ability to the subsequent phase (Stone et al., 2007). Stated differently, one phase creates adaptations which give way to higher performances in the next phase. As the restitution phase commences the athlete begins to recover and reach a new (superior) fitness level (supercompensation) (Zatsiorsky & Kraemer, 2006). This allows the athlete to then train in the next accumulation phase at a higher level allowing for greater adaptation. Over long periods of time the athlete becomes incrementally better with continued training.

Yet another strategy utilized is functional overreaching as detailed by DeWeese et al. (2015b). Overreaching allows the manipulation of either volume or intensity above that of which the athlete is accustomed to. After the substantial increase in volume or intensity, commonly lasting one week, the training stimuli is reduced. Upon return to normal levels of training an increase in performance can be expected (Pistilli, Kaminsky, Totten, & Miller, 2008). A further reduction in training below normal training levels (exponential taper) may produce even greater performance gains (DeWeese et al., 2015b). This is under the assumption proper training protocols and fatigue management are taking place. If an inappropriate level of stress is placed on the athlete, a progression may not occur, in fact a regression may occur making it difficult to return to normal levels.

Strength Training Means & Methods

Stone, O'Bryant, Garhammer, McMillan, and Rozenek (1982) developed a theoretical model for strength training. This seminal text outlines on a more practical level how a coach might go about planning strength training. The four phases in this model (hypertrophy, basic strength, strength-power, and active rest) are not entirely dissimilar than the program used in this endeavor. From the mechanisms in sections above, each of these phases are based around the after affects of the previous phase and serve to build on one another (phase potentiation). The hypertrophy phase, renamed high intensity exercise endurance by Stone et al. (2006), serves as a starting point. Outlined in the paper, the ultimate purpose of this phase is to increase work capacity and cross sectional area. Associations between CSA and force output established above make this a logical starting point.

With the goal of stimulating hypertrophy, a coach would prescribe exercise regimens which serve to create three primary stimuli of hypertrophy: mechanical tension, muscular damage and metabolic stress (Schoenfeld, 2010). Exercise selection during this block will be remedial in nature and entail gross movement patterns and large muscle masses (squats, presses, pulls). The remedial nature of this block will serve as not only a foundation from which to build physiologically but also pedagogically. For example, early renditions of weightlifting movements (pull to knee, mid-thigh pull or power position shrugs) may be used to enhance muscular size while simultaneously serving to aid in learning proper weightlifting technique (DeWeese, Bellon, Magrum, Taber, & Suchomel, 2015).

As the hypertrophy phase comes to a halt, the focus of training will shift to an emphasis on allowing the muscle to generate the most force possible using the enhanced musculature. The subsequent phase will take the form of comparatively lower volumes and higher intensities than the hypertrophy focused training phases. Moreover, this block will serve as a foundation for the further development of muscular force generation capabilities. This can be visualized in Stone et al. (1982) in Figure 9. As training progresses and each training phase is repeated it should be noted the weight lifted increases for the same emphasis. The athlete should strive to lift heavier weights in the second strength endurance phase compared to the first strength endurance phase, to evoke a greater adaptation. This should be pursued on both an acute and chronic level to ensure optimal adaptations. This requires focus and motivational energy as well as maximal intent to move the implement (Padulo, Mignogna, Mignardi, Tonni, & Ottavio, 2012), weight, or projectile as fast as possible. Exercise selection throughout this block will build on movements learned in previous blocks and also serve to progressively graduate toward weightlifting derivatives, employing larger ranges of motion, and allowing for greater loads to be prescribed.

After maximizing the ability of the musculature to generate force, explosiveness will rise to the primary foci of training. As both power and RFD (Haff & Stone, 2015; Taber et al., 2015) have been shown to be paramount to sporting performance, methods used to enhance aforementioned qualities will be specified. Much of these movements will be ballistic or semi-ballistic in nature. Ballistic movements allow for the athlete to accelerate the object, weight or projectile throughout the entire range of motion (Maloney, Turner, & Fletcher, 2014). Cormie et al. (2011b) demonstrate the ability of ballistic movements to increase power output, possibly allowing more specific adaptations to do specificity, and allow higher RFD possibly due to increase neural drive, rate of neural activation and coordination.

Plyometrics have often provided an avenue to bridge the gap between weight room strength and the demands of the competitive endeavor (Chu, 1983). These exercises take advantage of the rapid stretch of the musculotendinous complex and result in higher muscular force output (Markovic & Mikulic, 2010). Improvements in RFD (Cormie et al., 2011b) are theorized and probable with plyometric training, as such this sort of training has functioned as a integral training means to improve speed strength in sports. (Judge, 2007).

The velocity at which plyometric exercises can be executed makes this sort of stimuli a great option for enhancing ability to produce force quickly. Although very high values of power may be displayed in plyometric movements, consider sprinting is governed by ground reaction forces and exclusive implementation of plyometrics or potentiation complexes (Haff & Nimphius, 2012) is not recommended (DeWeese et al., 2015). Plyometric exercises and potentiation complexes most certainly have a distinct purpose in training programs as they supplement sprint training and assist in the training of the velocity end of the force velocity continuum. Plyometric exercises can be employed with medicine balls or other projectile objects during early portions of training to augment movements and enhance resistance to emphasize propulsive force production. This will allow the athlete a greater timeframe to produce propulsive forces allowing optimal positions to be demonstrated. In later portions of training, plyometric exercises can be employed to mimic the raw velocity exemplified on the track and train the nervous system to fire at an intensified rate. Further, the coach should have a rationale for utilizing plyometric training, as ground reaction forces resultant of plyometric type training can be up to 7x bodyweight (Markovic & Mikulic, 2010). Large volumes of this sort of work can be injurious if not done in moderation as high impact forces are associated with an increased injury occurrence (Grimston, Nigg, Fisher, & Ajemian, 1981; Clement & Taunton, 1980).

Weightlifting movements will be heavily prevalent as they may provide the single most effective type of training in athletic performance (Chiu & Schlilling, 2005). Concern still exists when the topic of including weightlifting movements or derivations in the programs of team or court sport athletes is broached. Perceived time required for athletes to learn, lack of understanding the potential benefits offered from incorporating these movements and potential injury concerns are commonly brought to light (Hedrick & Wada, 2008). Many of the sporting movements required in sport are of higher difficulty in comparison to weightlifting movements, especially the remedial movements such as the mid thigh pull (DeWeese, Serrano, Scruggs, &

Burton, 2013). Many coaches in a wide variety of situations have discovered a way to teach these movements to athletes so they may benefit. The quality coach is a problem solver and will unearth a medium through which these very beneficial movements can be taught. Understanding the potential benefit to other sporting movements has been outlined many times (Brewer & Favre, 2016; Comfort, Allen, & Graham-Smith, 2011a, 2011b; Suchomel et al., 2015). The role of the coach is to better serve the athlete through proper education. Hamill (1994) found per 100 participation hours of various activities weight training and weightlifting had the lowest two rates of injury. In opposition childhood soccer had the highest rate of injuries per 100 participation hours. The aforementioned concerns are met with much evidence to suggest the limitation on using weightlifting movement and derivatives is likely coach imposed. Coaches must not stand in the way of development but become the gatekeepers ushering our athletes to higher levels of success.

Briefly, weightlifting movements have been shown to enhance high-load speed strength (Hori, Newton, Nosaka, & Stone, 2005) sprinting and jumping ability (Hori et al., 2008; Stone, Byrd, Tew, & Wood, 1980; Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005), and exhibit mechanically specificity to most sporting movements (Suchomel et al., 2015). In addition, the ability to produce high ground reaction forces limits sprinting speed (Weyand et al. 2000), as such the overload attainable through weightlifting derivatives allows large ground reaction forces to be exerted into the ground in a rapid manner. McBride, Triplett, Davie, & Newton (1999) concluded the activities performed in the weight room should be adapted to meet the demands of the sport, when comparing strength and power between powerlifters, weightlifters and sprinters. Therefore, amplifying the sprinters ability to produce force quickly is the primary goal of weight training for many athletes, with particular interest to sprinters (Taber et al., 2015). Specificity in mind, an athlete cannot be too explosive; therefore weightlifting movements can serve to enhance an athlete's ability to be explosive. If explosiveness is a desirable trait for the sport in question, weightlifting movements and derivations will be an intelligent inclusion. Although a full review of the benefits of weightlifting for sports performance is beyond the scope of this text, interested readers will be guided to further reviews (Brewer & Favre, 2016; Suchomel et al., 2015).

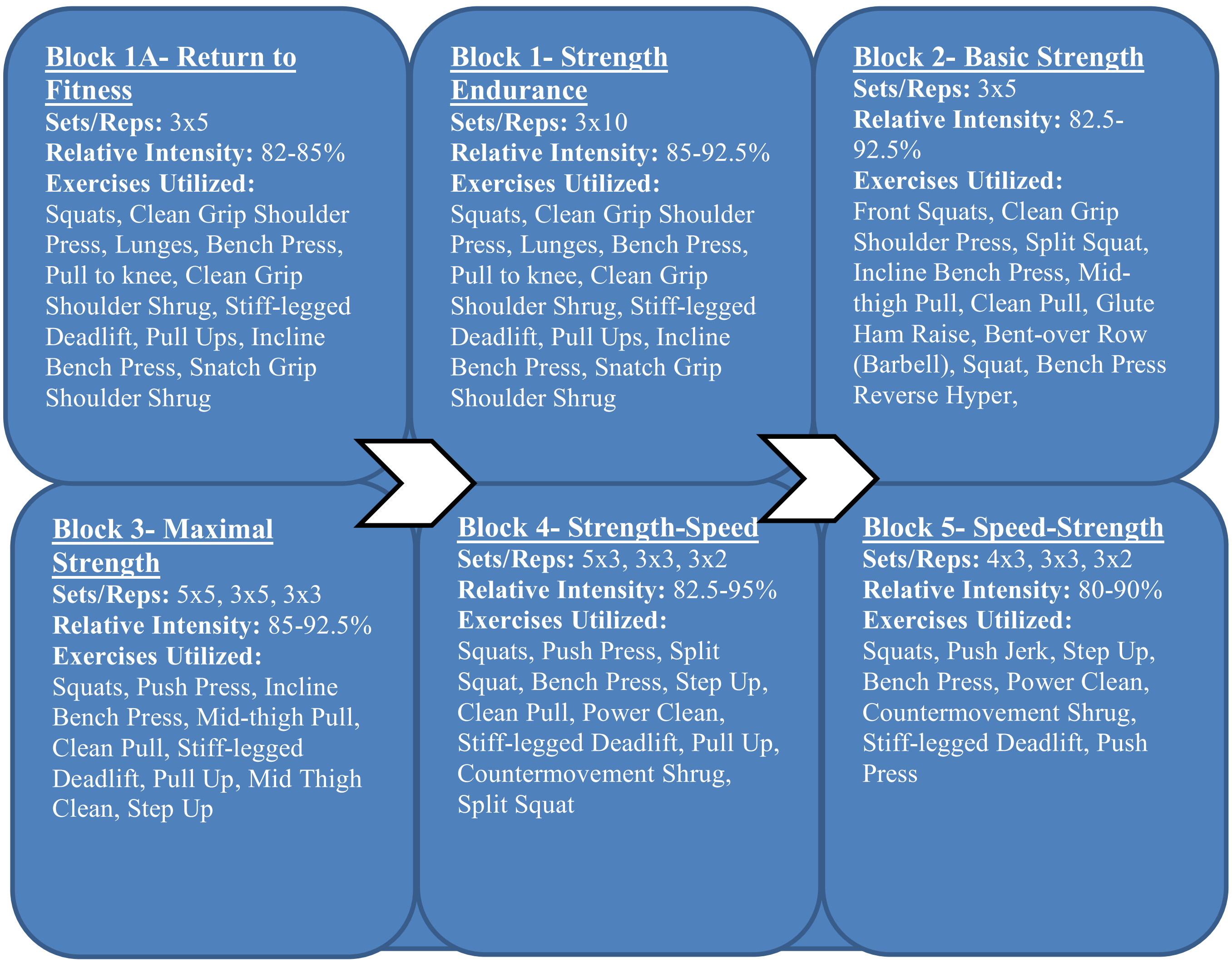

Figure 2. Strength Training Prescription

Important to note, none of the elements mentioned above are irreplaceable. A coach must create the best training possible for a given situation. All of the aforementioned features of the training process have a rationale behind them and work toward a unifying goal of sprinting as fast as possible. Routine monitoring processes should reside within the training program and assist the coach in evaluating the programs effectiveness. Strength training is a means to develop physical abilities in order to optimally perform the specific quality desired. This observation should not be overlooked as the weight room should operate as a breeding ground for the development of strength and explosiveness, which is then further enhanced with more specialized work in latter portions of the year. Visualized in the Figure 1, the strength training for this endeavor is observed. Movements progress from general to specific, large displacements to smaller displacements, and high force lower velocity to high velocity medium force outputs. Other examples of programs designed using phase potentiation can be found in Judge (2007), Stone et al. (1981), DeWeese et al. (2015), DeWeese et al. (2014a, 2014b) and Harris et al. (2000).

Short to Long Speed Development

Perhaps the most enticing experience of a sprints coach is to guide an athlete to the Olympic games, where he or she concludes the competition with the respective National Anthem playing over the loudspeaker while hoisting up a gold medal. This seemingly storybook ending has taken place 9 times, under the tutelage of world re-known sprints coach Charlie Francis in addition to 32 world records. Regardless of the absence or presence of performance enhancing agents, there is little doubt methods employed by Francis were effective.

Pioneered by the late Charlie Francis with support from Gerard Mock, Horst Hillie, Harry Jerome and Percy Duncan (1992) the “Short to Long” (S2L) approach focuses on the athlete’s ability to attain high sprinting velocities then shifts emphasis toward sustaining this velocity for greater distances. Logically, competitive sprint athletes cannot achieve maximal sprinting velocities without training. Utilizing, the S2L approach progressively permits the athlete to realize superior running velocities through a curriculum of focused efforts with the purpose of optimizing sprinting skill. Lest we forget, the ability to attain high horizontal sprinting velocity hinges on the athlete’s ability to accelerate (Ae et al., 1992; Tellez & Doolittle, 1984). Therefore, the S2L approach ensures maturation of the athlete’s accelerative abilities, which serve as the basis from which upright sprinting technique can be developed. Francis (1992) explains technique is a prerequisite to pursue sprinting excellence and high skill levels must be developed as early as possible.

Sprinters under Francis’ supervision were known to perform lower volumes of work compared with other training regimens in use at the time. Francis (1992) explains the interplay of volume and intensity and proceeds to elucidate higher volumes of work don’t develop power, high intensity efforts do. Francis believed only the highest intensity efforts would yield positive adaptations in speed. Large emphasis was then placed on recovery modalities and ensuring athletes were fresh for high intensity sprinting days.

While fresh, athletes are able to perform prescribed sprints at a high intensity when properly implemented. The high intensity nature of these activities yields high force outputs and desirable acceleration mechanics. In the case where an athlete has not yet learned proper acceleration technique, shorter sprints and resisted sprints provide learning opportunities for younger athletes or athletes needing a refresher course on how to properly accelerate. Conceptually shorter sprint distances save the athlete from large volumes of high impact forces and allow for enhanced learning environments. Quality within sprinting is the most important concept (Francis, 1992).

Conceptually, with the prescription of low volumes of sprint training, athletes have more opportunities to develop optimal technical execution. This approach ensures the athlete learn how to sprint 10 meters with satisfactory technique before progressing to 11 meters and so on. Continuing the mathematical learning analogy above, the student does not advance to multiplication if simple addition and subtraction are not at sufficient levels. In similar fashion, the athlete must not progress to longer sprinting distances or higher sprinting velocities until sufficient levels of accelerative abilities are attained. Just as mathematical skills come rather quickly to some and not so rapidly to others, differing methods may be required for certain athletes.

Once the athlete is able to demonstrate sound accelerative abilities, prescription will advance to longer distances. Implementing longer sprint distances, the athlete will learn to extend acceleration resulting in greater amounts of momentum, giving way to higher sprinting velocities. Therefore, within the S2L approach acceleration ability is paramount to furthering sprinting speed. When emphasis shifts to maximal velocity sprinting or speed endurance work, acceleration is just as important as it was in the shorter sprints. Success in maximal velocity sprinting and speed endurance work is grounded in the initial acceleration.

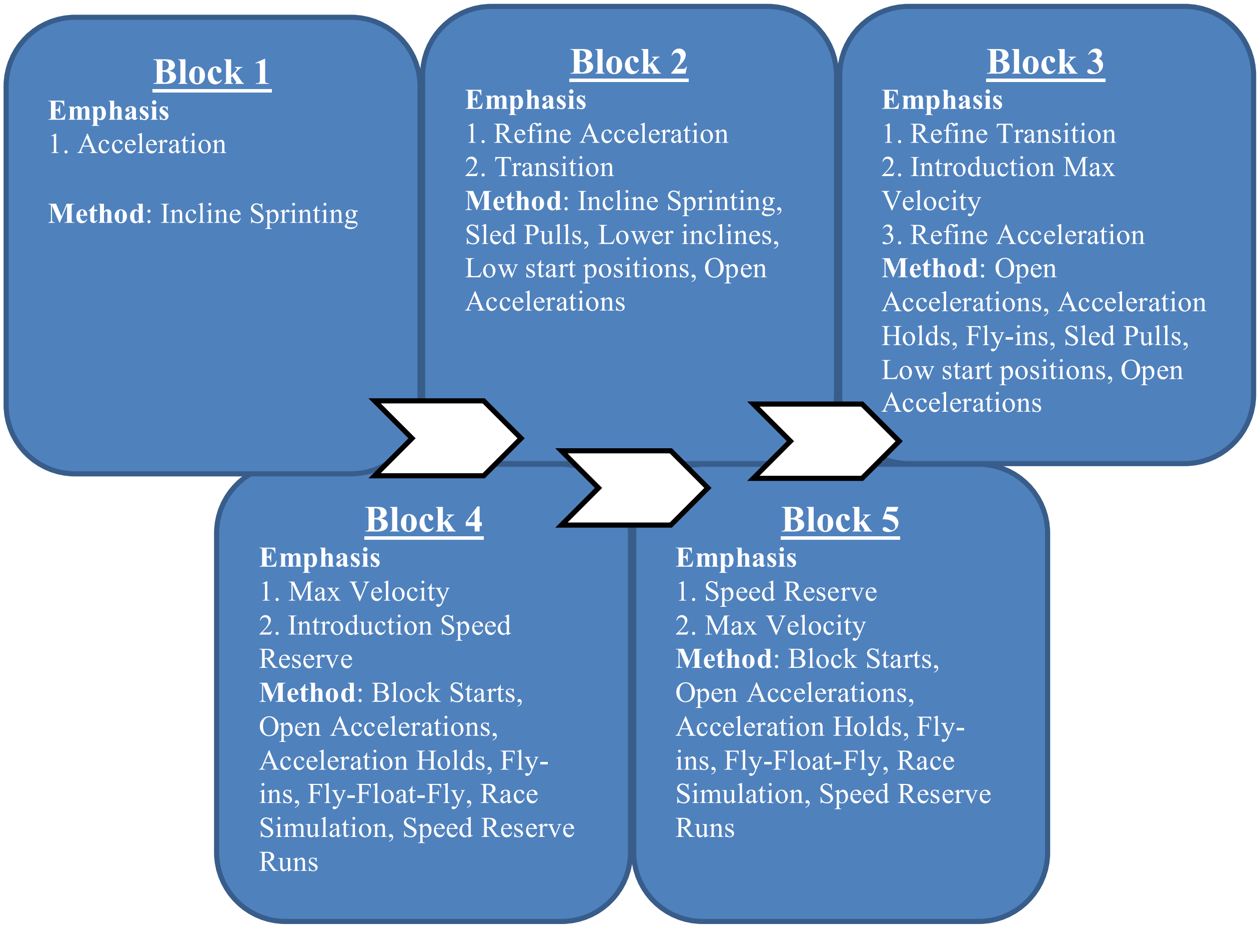

Figure 3. Speed Development Prescription

Logical in conception, the S2L requires a certain level of mastery before moving to higher levels of training. Contrastingly, other traditional models focus on physical capacities to endure longer distances. These approaches focus on energy system fitness, which can be adapted from the later stages of the S2L approach (Billat, 2001).

Conceptually, these programs suggest the average sprinter has more to gain by performing lengthy runs early on. The S2L approach is focusing on long term development of sprinting abilities. Additionally, other sprint training regimens try to simultaneously develop maximal sprinting speed and speed endurance. Discussed in the strength training section above, employing a method with multiple foci is sub-optimal compared with one focus. From a biological perspective, adaptations occur in a very specific manner to the demands imposed upon it. If contrasting stimuli are planned concurrently (speed vs. speed endurance), the downstream mechanisms creating adaptation will orient themselves toward more endurance type adaptations, leading to inferior pure speed adaptations (Wilson et al., 2012).

Additionally, much like the strength training above, sprint programs often develop qualities in unison, with an emphasis-de-emphasis structure. Notice this is quite different than simultaneously emphasizing two abilities. The emphasis-de-emphasis approach may only employ one or two exposures (drills/opportunities) to a secondary or tertiary emphasis, whereas emphasizing two abilities will have equal or somewhat equal exposure two both emphasized abilities. Termed vertical integration, all training qualities are being met within the training period but to highly differing degrees (Francis, 1992). A quality may only compose 1% of the work done. In this way training becomes a blending of training stimuli with one primary emphasis and several much smaller de-emphasized stimuli, where the volume of work done differentiates emphasis from de-emphasis.

Ultimately focusing on how absolute speed qualities can be advanced, it would seem counterintuitive to include slower runs, however, within the S2L approach slower work is employed. On days where restoration is the primary goal, longer distances of running termed tempo runs are prescribed. Tempo runs (Francis, 1992) are advised for the purposes of recovery. These runs are performed at an extensive tempo (65-75% maximum velocity), used to enhance recovery, work capacity, emphasize smooth/easy strides, and also may help enhance body composition (Francis, 1992). In conjunction findings from Suzuki et al. (2004) conclude light aerobic work generated a significant psychological effect and enhanced relaxation in collegiate rugby players. Leading to enhanced recovery and increased psychological states, this training is theorized to potentiate higher intensity sessions leading to superior adaptations. Assisting in the development of endurance type capabilities, these runs are the antipode of maximal velocity sprinting. Seemingly counterproductive, these runs are interspersed throughout the S2L approach. Additionally, mid-section, upper-body work, and general calisthenics can be employed during rest periods of tempo runs to enhance endurance capacities.

Director of Coaching for the British Athletic Federation from 1974-1994, Frank Dick concludes developing maximum sprinting speed rests squarely on developing high technical skill levels, improving relevant physical abilities, and progressing toward expressing this technique in training and competition (Dick, 1989). The S2L approach integrated with Conjugate Successive Sequencing fulfills both of these tenets. First, establishing sound technique is accomplished by administering shorter sprints to ensure critical accelerative abilities are established. This entails the ability to produce large propulsive forces from many different positions. As the body merely pushes in accordance with alignment and position of the limb and its musculature, irrespective of direction, accelerative mechanics depend on the proper position of limbs to direct forces in the optimal (propulsive) manner. Logically, this result can only be obtained from deliberate practice of acceleration through sensible training exposures administered by the coach. Second, physical abilities are improved through a scientifically backed plan with the ultimate goal of enhancing strength and explosive strength. As technical components improve, physical abilities improve assisting and bolstering each other along the way. The final section will detail the coupling mechanisms between Conjugate Successive Sequencing and the Short to Long approach.

Incorporating Short to Long & Conjugate Sequential Sequencing Strategies in a Seamless Manner

Strength and the ability to produce force quickly are without a doubt some of the most important abilities in sport (Haff & Stone, 2015; Taber et al., 2016). Within the context of sprinting, accelerative abilities lay the foundation for future success (Tellez & Doolittle, 1984). Summating the previous sentences, these two properties form the basis from which Seamless Sequential Integration was founded and will be the targets for training and adaptation.

While the development of speed is most critical to a sprinter, in early portions of speed development the coach and athlete can use slower velocities of movement to learn how to accelerate. Sprint velocity may be decreased as a result of resisted sprinting. Research corroborates not only that incline sprinting produces slower velocities but also does so with higher pushing times (Cross, 2016; Slawinski et al., 2008). This could be valuable to athletes' refinement of acceleration. While investigating incline sprinting, Gottschall and Kram (2005) showed raising the ground closer to the athlete's foot through incline sprinting decreased forces at impact and necessitates greater propulsive forces. In line with previous research by Rabita et al. (2015) and Morin et al. (2011) the importance of orienting forces properly was found to be a critical factor in accelerated sprinting success. Thus, incline sprinting is theorized as a way to enhance accelerative abilities (Bingham, Wagle, Fiolo, & DeWeese, 2016).

Incline sprinting, coupled with an accumulation block of weight training, can suppress the capability to produce high values of RFD (Verhoshansky & Siff, 2009). Established in multiple works, RFD is of utmost importance for sprinting ability (Clark & Weyand, 2014; Slawinski et al., 2010) and chronically diminishing RFD is never a desired outcome. However, to pursue enhancements in RFD at more influential time points, suppression is needed. Investing in muscular size early will allow for the potentiation of RFD later. A common misstep is to desire high values of RFD year round. With the former in mind, the decision to pair acceleration work is done with the knowledge of an increase in pushing time on the incline. Hypothetically, this allows the athlete to develop accelerative abilities at lower velocities through forces exerted over longer pushing timeframes, while RFD is suppressed. This pairing situates athletes in a position to develop necessary musculature for optimal force production in later phases, learn proper accelerative mechanics and produce large propulsive forces important for graduating toward higher level sprinting. An additional teaching opportunity resides in the multi-throws/jumps department. As Debaere et al. (2013) demonstrate the importance of proximal to distal firing of muscles and did not find evidence suggesting there is a stretch shortening cycle at the knee during a 10m sprint. Due to this finding, coaches may employ concentrically dominant jumping and throwing movements and progress toward movements heavily based on the stretch shortening cycle. Moreover, Shepherd (2008) indicates concentric strength expression is a key acceleration determinant. Using static start or concentrically emphasized throws or jumps may foster further enhancements in learning the skill of accelerating.

Moving away from concentrated loads on the incline and high volumes of work in the weight room, emphasis will shift in both areas. As indicated in Figures 2 & 3, sprint training moves toward higher velocity movements and weight training moves toward lower volumes and slightly higher velocities of movement when compared to the first block of training. The rationale behind using gradually faster movements is to allow the athlete to progressively advance to higher velocities of training while permitting the refinement of propulsive force output and accelerative mechanics. As suppression of RFD is still in effect from the previous accumulation block of training, incline sprinting will still be employed to allow for the further enhancement of acceleration.

Indicating delivery of force magnitude and orientation the knee or height of the thigh is an important aspect commonly seen in upright portions of sprinting. Now desiring higher levels of inclination, this delivery is just as important during accelerated running. In a progressive study previously detailed Rabita et al. (2015) reports the ratio of force application technique is the key parameter in deciding performances differentiating highly trained athletes. Further, Morin et al. (2011) found force application technique as a determining factor in 100m sprint performance. Moreover, Morin and colleagues link this force application technique to the forward inclination of the body. As a result of sled towing Spinks, Murphy, Spinks, and Lockie (2007) found an increase in the trunk angle of a group of high caliber rugby, soccer and Australian football athletes. Sled towing was said to aid in the adoption of inclination angles close to that of a block start. With a further trunk or inclination angle, applying forces “down and back” will provide greater efficiency serving to boost sprint velocities.

As any effective teacher or coach knows, no one method is all-inclusive and many methods serve as the best recipe. In accordance, sled towing is used as another training stimulus to allow for further refinement of accelerative abilities. It is recommended loads associated with a discrepancy of no more than 10% of sprinting velocity should be employed with sled towing. However, recent work provides evidence heavier loads may have beneficial impacts on acceleration (Cross, 2016). Further investigation on this topic is warranted.

Movement from accumulation to transmutation focused weight training which allows for the development of higher forces and more specific abilities to be trained. The athlete should then begin to dissipate fatigue manifested in previous blocks of training. With the unveiling of fatigue and newfound musculature, higher levels of muscular force can be realized and used for the attainment of higher sprinting velocities. Several changes will begin to occur at this point, as a fundamental shift is occurring toward faster movements within speed development and in the weight room.

After fine-tuning the athlete's ability to accelerate from many different training exposures and developing the athlete's force production profiles to higher levels, it is time to move into the realization phase of training. This phase of training serves to "realize" or help the athlete grasp physical and technical abilities developed during early training periods. The emphasis on speed development moves toward maximal velocity sprinting and will progress onward to speed endurance work. As the emphasis on the track shifts toward the highest velocities seen thus far, training in the weight room will follow suit. Further reductions in volume and increased intensities will be prescribed in the weight room. Advanced weightlifting movements focusing on moving weights as quickly as possible will also be employed. High movement velocities will elicit improvements in RFD, which serve as the basis of sprinting success. Training at this time of the year represents the speed side of the force velocity continuum. As discussed before, high force movements will be prescribed. The majority of movements implemented will be very rapid in nature compared to slower renditions prescribed in earlier blocks.

The scope of this manuscript is to outline the process by which training decisions have been made. However, it is implausible, to provide a rationale for every decision made in the training plan. Now possessing the understanding of physiological underpinnings of sprinting speed and common methods used to elicit enhancement in speed, the coach can begin to implement this system. Mastery of all the above sections is not a desired outcome. Providing coaches with knowledge so they may pursue sprinting excellence with athletes is plausible. Further, there is no evidence to suggest there are diminishing enhancements associated with the pursuit of greater sprint speeds. Coaches are urged to plan diligently, coach intelligently, and aspire to serve athletes to the best of their ability.

CHAPTER 3

Outcomes of an Integrated Approach to Speed and Strength Training with an Elite-Level Sprinter

[1]Eric D. Magrum, [1]Brad H. DeWeese, [1]Kimitake Sato, [1]Michael H. Stone

[1]*Exercise and Sport Sciences, East Tennessee State University, Johnson City, TN, USA*

Eric Magrum, BS, CSCS, USAW-Corresponding Author
Department of Exercise and Sport Science
East Tennessee State University
PO Box 70671
Johnson City, Tennessee, 36704
Email:Magrum@etsu.edu

Brad DeWeese, Ed.D
Assistant Professor
Department of Exercise and Sport Science
East Tennessee State University
PO Box 70671
Johnson City, Tennessee, 36704
Email: dlive11@gmail.com
Office Phone: (423) 439-5844

Kimitake Sato, PhD
Assistant Professor
Department of Exercise and Sport Science
East Tennessee State University
PO Box 70671
Johnson City, Tennessee, 36704
Email: satok1@etsu.edu
Office Phone: (423) 439-5138

Michael H. Stone, PhD
Professor and Sport Science Laboratory Coordinator
Department of Exercise and Sport Science
East Tennessee State University
PO Box 70671
Johnson City, Tennessee, 36704
Email: stonem@etsu.edu
Office Phone: (423) 439-5796

Word Count 2,799

Outcomes of an Integrated Approach to Speed and Strength Training with an Elite-Level Sprinter

Abstract

The purpose of this study was to observe changes in sprint velocity, ground contact time, and peak force demonstrated by a competitive sprinter following an integrated approach to speed development and strength training. As part of an ongoing monitoring procedure the participant completed 20m sprint testing through an optical measurement system and isometric-strength testing before and after each phase of training. Sprint velocity, ground contact time and peak force were analyzed using Tau-U, smallest worthwhile and percent change statistics. Results indicate sprinting velocity statistically improved while changes in peak force were practically significant and ground contact time remained trivial throughout the investigation. Results lead investigators to suggest the implementation of a periodized approach merging technical skill and the development of physical abilities. The integrated approach provided a transfer of training effect and may have been the primary source of sprint enrichment.

Keywords: Speed, Strength, Short to Long, Seamless Sequential Integration, Elite

Introduction

Coaches and practitioners around the world seek to gain insights on how to strategize, structure, and devise training programs to enhance sprint speed. The argument can then be made that sprinting speed is the most sought after ability in sport. (Bellon, 2016; Morin, Edoudard, & Samozino, 2011; Nagahara, Naito, Morin, & Zushi, 2014; Rumpf, Cronin, & Schneider, 2014). Sprinting can be defined as an un-paced bi-pedal cyclical movement, executed at maximal intensity, and commonly lasting 15 seconds or less. (Ross, Leveritt, & Riek, 2001). Despite the time constraint within this strict definition, the maximal intensity associated with longer events like the 200 and 400 m races, lends credence to their classification as sprint events. Furthermore, evidence indicates the 60 second mark as the threshold for an even split between aerobic and anaerobic contributions to maximal sustained efforts (Stone, Sands & Stone, 2007). Evidence also leads investigators to believe sprinting speed in humans is largely independent of substantial aerobic contributions under 60 seconds (Weyand, Lee, Martinez-Ruiz, Bundle, Bellizzi & Wright, 1999). This would create a situation where locomotor activities completed in under 60 seconds should be considered sprinting events.

In direct pursuits of speed, which determine the winner as the athlete covering a respective distance in the shortest amount of time, it is evident that sprinting abilities are strongly related to an athletes maximal running velocity (Bruggeman & Glad, 1990; Mac'kala, 2007; Mann, 2013; Volkov & Lapin, 1979;). Attaining maximal velocity is heavily dependent upon many factors including: the ability to produce large mass-specific forces (Delecluse, 1997; Seitz, Reyes, Tran, Villarreal & Haff, 2014; Weyand, Sternlight, Bellizzi & Wright, 2000), ability to produce force rapidly (Clark & Weyand, 2014), ability to coordinate movement at high velocities (Missitzi, Geladas & Klissouras, 2004), inter-muscular coordination (Coh, Zvan, Velickovska, Zivkovic & Gontarev, 2016), technical ability (Morin et al., 2011; Rabita et al., 2015), and most notably, genetics (Eynon et al., 2013; Lucia, Moran, Zihong, & Ruiz, 2010; MacArthur & North, 2004; Scott et al., 2009; Wang et al., 2013).

The acceleration phase has been known to dictate the successfulness of the ensuing maximal velocity phase (Van Ingen Schenau, Koning & de Groot, 1994). Evidence suggests even the fastest 100m ever run was completed while decelerating near the finish (Krzysztof & Mero, 2016). Emphasizing a steadfast ability to accelerate and delaying maximal velocity serves to minimize deceleration in the latter portions of the sprint. Further, the set up for and execution of the sprint start lays the foundation for the proceeding phases of the sprint (Coh, Jost, Skof, Tomazin, & Dolenec, 1998; Milanese, Bertucco, & Zanacanaro, 2014). Without proper execution of and transition between previous sprint phases, the maximal velocity phase may prove to be insufficient and leave something to be desired. Stressing the importance of a holistic approach in sprinting, one cannot focus solely on one phase of the sprint but must configure a way in which all phases of the sprint are learned in sequential order to reinforce sprint specific physical literacy as well as technical proficiency.

Bolger, Lyons, Harrison and Kenny (2015) expose a need for longitudinal observations of competitive sprinters and the resistance training protocols used to enhance performance. Utilizing a novel approach, seamless sequential integration (DeWeese, Sams, & Serrano, 2014a; 2014b), strives to advance an athletes' technical skill while simultaneously developing the physical abilities underpinning technical prowess. Therefore, the primary purpose of this study was to observe changes in sprint velocity, ground contact time, and peak force in an elite-level sprinter following an integrated approach to speed development and strength training.

Methods

Participant

The athlete was a professional U.S.A. Track & Field athlete competing in the 400m (age: 28 years, body mass: 89.4kg, height: 182cm). Qualifying as elite, the athlete appeared in multiple World Championships and Olympic games. Accolades include Olympic medalist, World Indoor Championships medalist, and multiple NCAA Championship Qualifying appearances. The athlete has been competing in track and field for approximately 10 years and has been training 4-7 times per week. Accolades aside, the subject of this endeavor should be considered elite, as set by the standards of Sides (2014). The study was approved by the universities institutional review board.

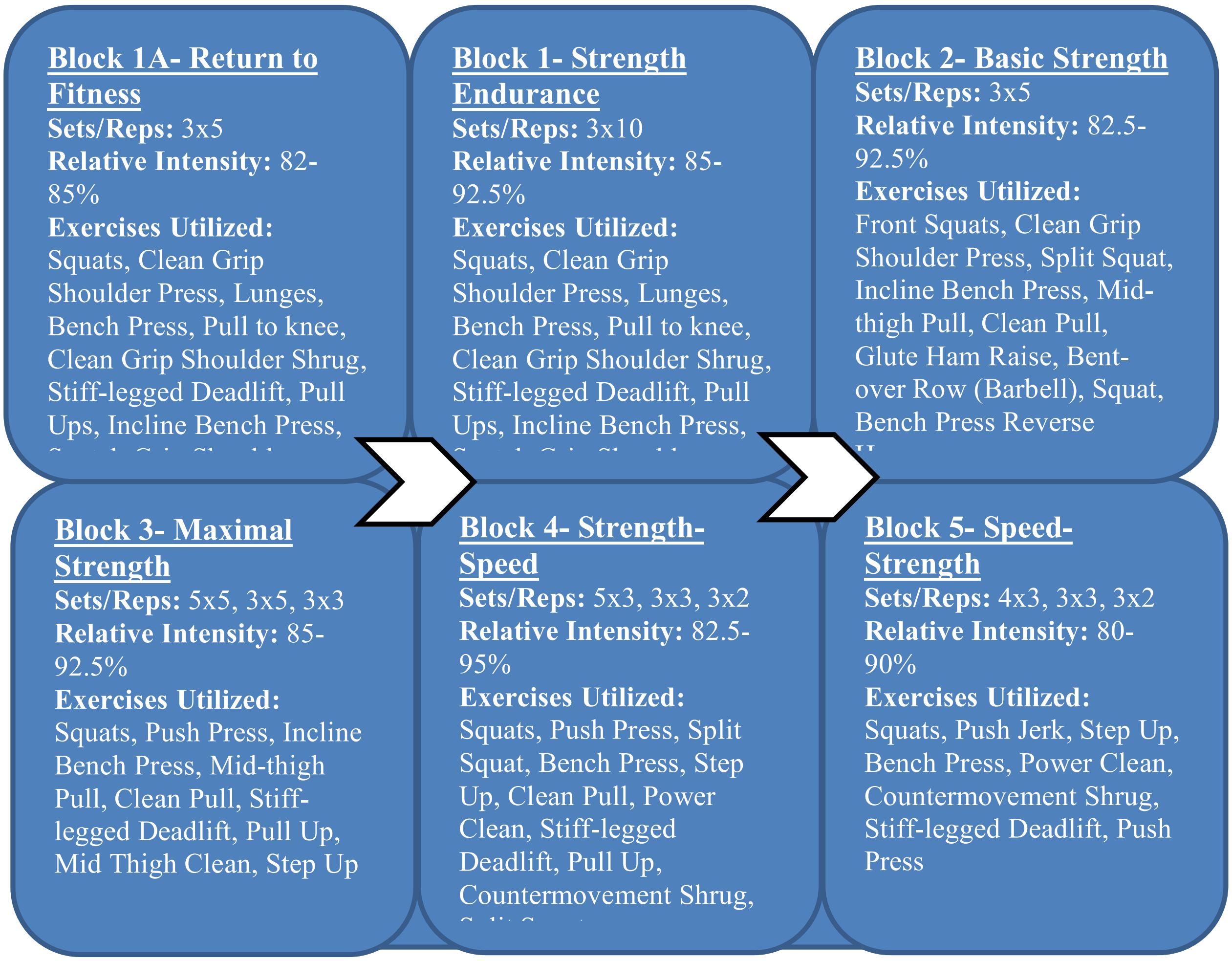

Figure 1. Strength Training Prescription

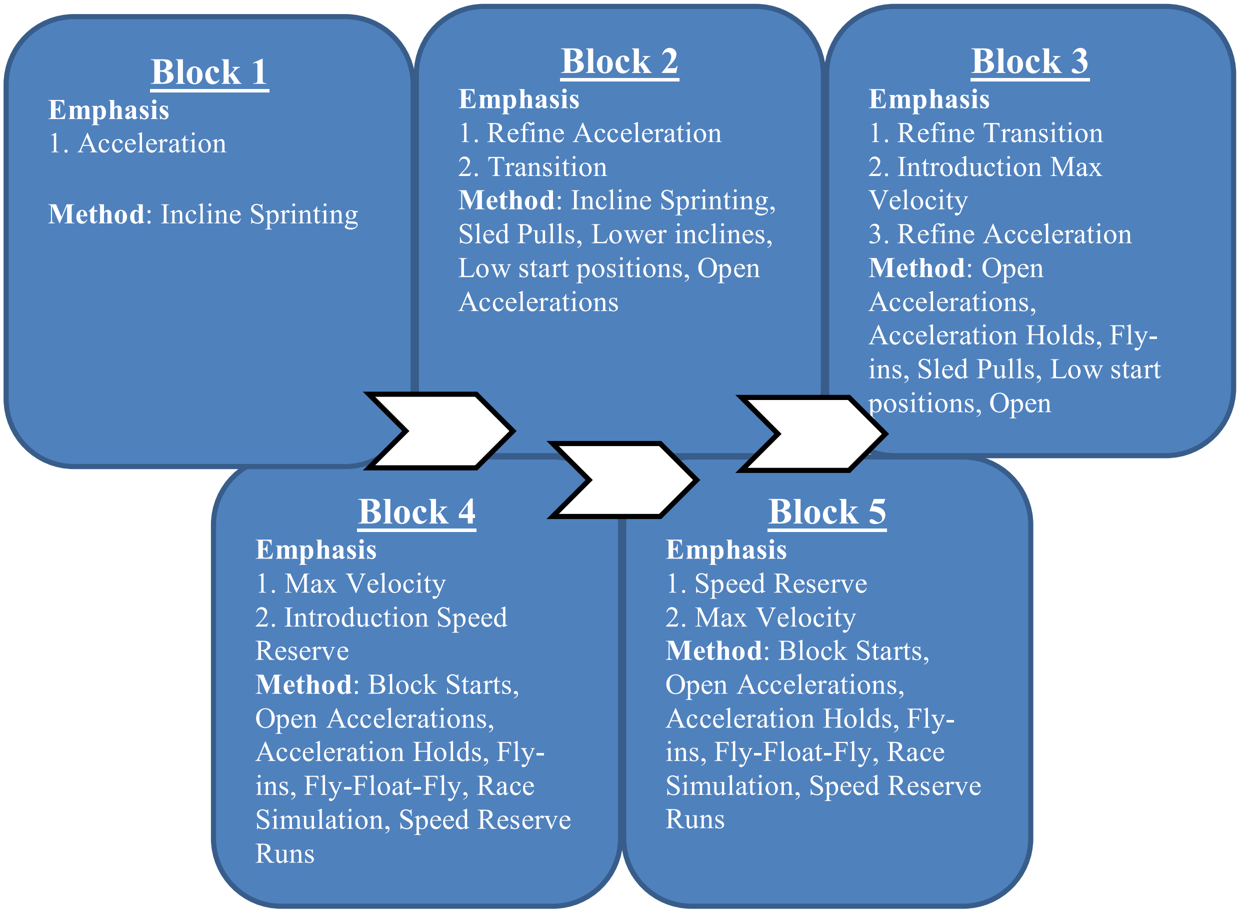

Figure 2. Speed Development Prescription

Procedure

The athlete was tested before the start of the first phase of training, and was tested after the proceeding phases of training for performance measures. These tests included 20 meter sprints from a block start and an isometric mid thigh pull. The sprint testing took place on Mondays, with the isometric mid thigh pull performed on Wednesdays of the same week. The testing protocol was identical for each time point. After the participant performed the standard warm up, three 20m accelerations were performed. The sprint trials were conducted on a synthetic track in an indoor athletic stadium. The participant wore his own training attire and spikes.

Sprinting Assessment

Sprint metrics were collected using the OptoJump Next system (Microgate, Bolzano, Italy). This measurement system utilizes 32 infrared LED's sampling at 1000 Hz encased within transducer and receiving bars (1 meter each) to collect data. Three sprint trials were used in the analysis of performance of T1-T3 and four trials were used in T4 and T5. Data from sprinting trails were used to evaluate ground contact time and sprinting velocity.

Strength Assessment

The isometric mid thigh pull tests were performed on dual force plates (RoughDeck HP, Rice Lake WI) and sampled at a frequency of 1000Hz. The data was analyzed using customized LabView software, a program used specifically for analyzing data from these force plates.

During the isometric mid thigh pull the athlete was placed into the 'power position' and pre-determined bar height to standardize testing sessions. The participant is familiar with this position from the various exercises performed containing this position. The athlete was taken through two warm up trials at 50% and 75%. The next two trials were a 100% maximal effort with strong encouragement from the testing staff. The athlete's hands were taped to the immovable bar to negate hand strength from being a limiting factor in the performance of the pull. Methodology is similar to what has been previously suggested by Kraska et al. (2009).

Statistical analysis

Tau-U effect size statistics (0-100%) were calculated to determine overlap and improvement between the phases of training (Parker, Vannest, Davis, & Sauber, 2011). Tau-U effect sizes can be interpreted as questionable ($X \leq 65$), effective ($66 \leq X \leq 92$) & very effective ($X \geq 93$) (Rakap, 2015). Smallest worthwhile change (SWWC) (smallest meaningful change) was calculated for the dependent variables by multiplying the pooled standard deviation of all monitoring sessions by 0.3 (Halperin, Hughes, & Chapman, 2016; Hopkins, 2004). Percent change was configured for the dependent variables between the baseline measurement and the final monitoring session. Statistical significance for all variables was set at ($p \leq 0.05$). Tau-U calculations were completed utilizing a specialized web based calculator for single case research designs (Vannest, Parker, Gonen, & Adiguzel, 2016). All other calculations were calculated utilizing Microsoft Excel 2010 version 14 (Microsoft Corporation, Redmond, WA, USA).

Results

Sprinting Velocity

Throughout the duration of the training period sprinting velocity increased. Terminal velocity significantly increased at T3 and T5 (p=0.029, 0.008), while T4 nearly reached statistical significance (p=0.051). After initially decreasing below the SWWC, sprinting velocity increased and remained above the SWWC for time points T3-T5. Measured by Tau-U effect size the magnitude of change was largest for T5 (ES=1.00), followed by T3 (effective, ES=0.88), T4 (effective, ES=0.73) and T2 (ineffective, ES=0.09).

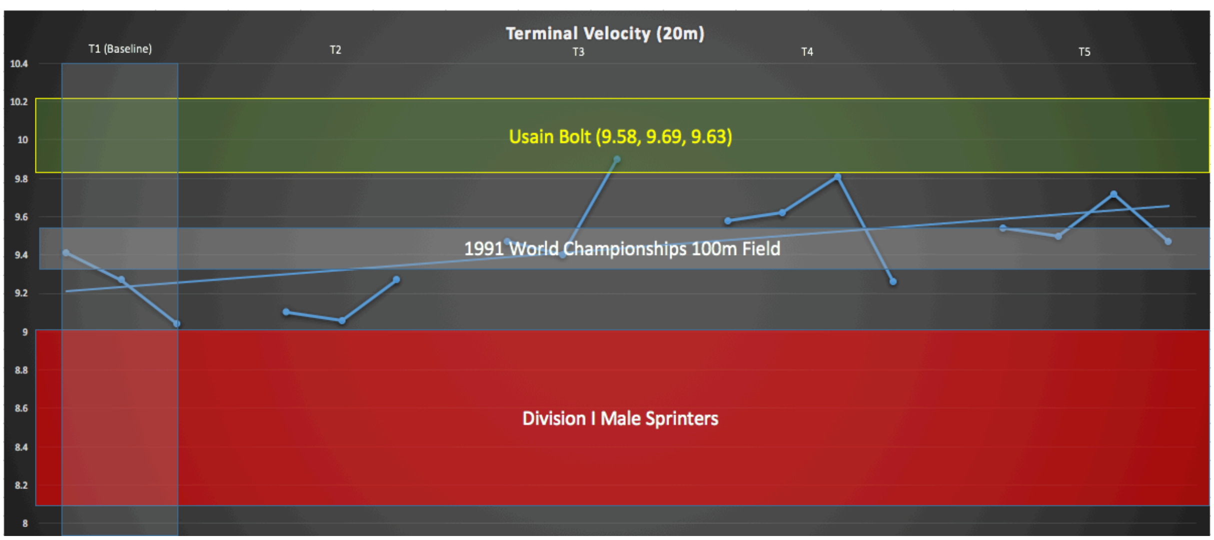

Figure 3. 20m Performance Comparison

Ground Contact Time

Ground contact times (GCT) remained relatively unchanged throughout the training period. Magnitude of change were all within the ineffective range T2 (ES= -0.22), T3 (ES= -0.11), T4 (ES= -0.00) and T5 (ES= -0.16). All testing sessions remained within the SWWC, T3 (p=0.82) was the exception, after which GCT returned to within the limits of the SWWC. No performances reached statistical significance.

Table 1. Performance outcomes from the monitoring process

	T1 (Baseline Testing)	*T2*	*T3*	*T4*	*T5*	*T5-T1 % Change*
Mean Velocity (m/s)	9.24m/s	9.14m/s	9.59m/s	9.56m/s	9.55m/s	(+3.35%)
Terminal Velocity (m/s)	9.41m/s	9.27m/s	9.9m/s	9.81m/s	9.72m/s	(+3.29%)
Mean GCT (s)	0.0976s	0.0970s	0.0963s	0.0977s	0.0975s	(-0.61%)
Terminal GCT (s)	0.0960s	0.0960s	0.0900s	0.0940s	0.0940s	(-2.08%)
Mean Isometric Peak Force (N)	3104.70	3124.41	3137.76	3613.75	DNP	(+16.39%)
Isometric Peak Force (N)	3215.49	3222.81	3153.49	3685.67	DNP	(+14.6%)

Isometric Mid-Thigh Pull

Isometric force production increased throughout the monitoring period and showed a large magnitude of change from baseline (T1) to time point 4 (T4). With an effect size of 1.00, there was a meaningful but not statistically significant (p=0.052) difference between T4 and baseline measures. The first three testing time points (T1-T3) remained within the SWWC while the last time point (T4) exceeded it.

Discussion

The purpose of this study was to observe changes in sprint velocity, ground contact time, and peak force in an elite-level sprinter following an integrated approach to speed development and strength training.

The athlete displayed high levels of sprinting success in competitive history and when compared to other similarly talented athletes (Figure 3.). After an initial regression noted in 20m sprint velocity, performance steadily increased. Many factors could be responsible for the initial decline in sprint performance. This may be due to the novel means and methods of a new training environment or the temporary downfall of explosive strength needed for sprinting (Verhoshansky & Siff, 2009) resultant from high training volumes relative to the athlete's physical condition. It is probable that a combination of both the above factors played a role in the decreased performance from the initial testing session.

Following a concentrated training block of acceleration, the athlete attained the highest running velocity throughout the study in T3. This was likely due to the focus on how the sprinter should properly apply forces to the ground, as orientation of forces has been shown to differentiate elite from sub-elite sprinters in 40m (Rabita et al., 2015). This was conveyed through many different medicine-ball throws, technical drills and sprints concentrating on powerful movements emphasizing horizontal translation.

Terminal velocity and mean velocity increased (3.29% & 3.35%) by the end of the investigation, and as time progressed, sprinting velocity improved as a result of training. This is likely due to the incorporation of retaining stimuli allowing the athlete to further refine his accelerative and maximal velocity abilities while focusing on maintaining velocity for longer durations. Additionally, follwing a periodized training plan, volume of work tapered off and focused on applying force rapidly through more ballistic activities, which is previously shown to elicit positive improvements in RFD (Van Cutsem, Cuchateau, & Hainaut, 1998). While RFD supports short and long sprint success, the implementation of a short to long speed development approach seems to be more appropriate when compared with others. (DeWeese, Williams, Sams, & Bellon, 2015; DeWeese, Bellon, Magrum, Taber, & Suchomel, 2015).

While supporting elite track and field athletes, sport scientists and coaches should focus on enhancements less than 1%. Enhancements observed in this endeavor exceed what is deemed as the smallest worthwhile change by Hopkins (2005). Therefore, authors conclude enhancements in sprinting velocity not only reached statistical significance, but most importantly, allows coaches to interpret the outcomes of training.

Ground contact times showed a reduction at T3, but thereafter returned similar to baseline measures and remained relatively stable throughout the study. Terminal GCT and mean GCT showed reductions (2.08%, 0.61%) as training progressed to longer duration sprints. To no surprise the shortest GCT occurred in T3 alongside the highest terminal and mean sprinting velocity, just as Mann (2013) indicates faster sprinters spend less time on the ground. It is desirable to see GCT reduced to an optimal range, especially as sprint distances increase. This may be due to the focus of training shifting to low volume and high rates of force development in the weight room paired with longer bouts of sprinting stimuli. While the emphasis in sprinting progress to longer distances, the emphasis in the weight room remains improving RFD, as volume accumulation is the main decrement in RFD. Mitigating the accumulation of work is a way to ensure RFD is either enhanced or maintained. Should volume go unmanaged, undesirable fiber type transition and mitochondrial biogenesis may occur (Coffey & Hawley, 2007) leading to a suppressed ability to generate RFD. While RFD underpins sprinting performance, this may lead to a decrease in sprint performance. Periodized plans serve to accentuate physical attributes to preserve and even enhance physical abilities for prioritized competitions.

Interestingly enough, while the training produced increased velocities GCT did not reach statistical or practical significance. While brief ground contacts are the aspiration of many sprints coaches, without the ability to produce sufficient forces during these brief time periods, velocity is lost. With the aforementioned increase in sprinting velocity and maintenance of GCT, the authors postulate the improvements in speed can be attributed to an enhanced ability to produce mass-specific forces in similar timeframes. Further, this would mean an increase in the rate at which force is produced, which has been previously shown to underpin sprinting performance (Clark & Weyand, 2014; Weyand et al., 2000). Similar to findings from Harris et al. (2000) strength and speed parameters were improved using a periodized training program. This sequential model is founded upon findings from Bodine et al. (1982) who concluded a muscles force capability is proportional to it's cross sectional area (CSA). Therefore, a special sequence of training stimuli aimed at enhancing CSA may provide further enhancements in force and rapid force production.

Peak isometric force and mean peak isometric force eluded any practical change until the final testing session (T4). During the final testing session mean isometric peak force (+16.39%) and peak force (+14.6%) increased to a practically significant degree (ES 1.00) but remained statistically insignificant ($p=0.052$). This may be due to the lag effect of training otherwise known as the delayed training effect (Stone, Stone & Sands, 2007). It may also be noted, increases in strength did not occur simultaneously with increases in speed and proved to be delayed just as was found by Stone et al. (2003). This could provide support to suggest the enhancement of sprint velocity may come initially through neurological adaptations (Ross, Leveritt, & Riek, 2001) and may also continue to provide further positive adaptations when more physiological adaptations occur allowing enhanced force and rate of force production (Stone et al., 2003).

Summarizing the findings suggest that RFD capability improved as higher velocities were attained even though ground contact times showed little alteration. Increases in strength, as observed in the isometric mid-thigh pull, may have allowed the athlete to increase the rate at which force is produced.

Application

The results of this endeavor concluded with enhancement of sprinting velocity and isometric force production. Sprint velocity is primarily dictated by the forces applied to the ground, and as force production increases so does velocity. Further, the brevity of footfalls displayed by elite-level sprinters does not allow for maximal force production. Therefore, the ability to produce large amounts of force in a very small time window (RFD) becomes a major contributor to sprinting success. RFD can be enhanced through a multitude of means and methods, but can be developed in simultaneous fashion to sprint technique. The synchronized development allows the paired enhancement of both the ability to produce and utilize RFD in a manner which supports greater sprint ability.

These findings lead investigators to suggest the implementation of similar means for simultaneous development of strength and speed. Implementing a similar program does not ensure elite-level attainment, however, replicating similar tactics may allow for the enhancement of relative sprint speed. Practitioners are urged to think critically and begin to optimize a training plan for their specific situation utilizing the information offered.

Acknowledgements

No acknowledgements reported by the authors.

Disclosure statement

No potential conflict of interest reported by the authors.

References

Bellon, C. (2016). The relationship between strength, power, and sprint acceleration in division I men's soccer players. In E. T. S. University (Ed.).

Bodine, S. C., Roy, R. R., Meadows, D. A., Zernicke, R. F., Sacks, R. D., Fournier, M., & Edgerton, V. R. (1982). Architectural, histochemical, and contractile characteristics of a unique biarticular muscle: the cat semitendinosus. *Journal of Neurophysiology, 48*(1), 192-201

Bolger, R., Lyons, M., Harrison, A. J., & Kenny, I. C. (2015). Sprinting performance and resistance-based training interventions: A systematic review. *Journal of Strength and Conditioning Research, 29*(4), 1146-1156

Bruggeman, G. P., & Glad, B. (1990). Time anlaysis of the sprint events. Scientific research project at the games of the XXIVth Olympiad- Seoul 1988: final report. *New Studies in Athletics, 1*, 11-89

Clark, K. P., & Weyand, P. G. (2014). Are running speeds maximized with simple-spring stance mechanics? *Journal of Applied Physiology, 117*, 604-615. doi: 10.1152/japplephysiol.00174.2014

Coffey, V. G., & Hawley, J. A. (2007). The molecular bases of training adaptation. *Sports Med, 37*(9), 737-763

Coh, M., Jost, B., Skof, B., Tomazin, K., & Dolenec, A. (1998). Kinematic and kinetic parameters of the sprint start and start acceleration model of top sprinters. *Gymnica, 28*, 33-42

Coh, M., Zvan, M., Velickovska, L. A., Zivkovic, V., & Gontarev, S. (2016). Biodynamical factors of running speed development. *Research in Physical Education, Sport and Health, 5*(1), 17-22

Delecluse, C. (1997). Influence of strength training on sprint running performance. *Sport Med, 24*(3), 147-156

DeWeese, B. H., Bellon, C., Magrum, E. D., Taber, C., & Suchomel, T. (2015). Strengthening the springs-Improving sprinting performance via strength training. *Techniques, 9*, 9-20.

DeWeese, B. H., Sams, M., & Serrano, A. (2014). Sliding toward Sochi-part I: A review of programming tactics used during the 2010-2014 quandrennial. *NSCA Coach, 1*(3), 30-43

DeWeese, B. H., Sams, M., & Serrano, A. (2014). Sliding towards Sochi-part II: A review of programming tactics used during the 2010-2014 quadrennial. *NSCA Coach, 1*(4), 4-7

DeWeese, B. H., Williams, J. H., Bellon, C., & Sams, M. L. (2015). The Nature of Speed.

Techniques 8, 10-22.
Eynon, N., Hanson, E. D., Lucia, A., Houweling, P. J., Garton, F., North, K. N., & Bishop, D. J. (2013). Genes for elite power and sprint performance: ACTN3 leads the way. *Sports Med, 43*, 803-817. doi: DOI 10.1007/s40279-013-0059-4
Halperin, I., Hughes, S., & Chapman, D. W. (2016). Physiological profile of a professional boxer preparing for Title bout: A case study. *Journal of Sport Sciences*, 1-8. doi: 10.1080/02640414.2016.1143110
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. *Journal of Strength and Conditioning Research, 14*(1), 14-20
Hopkins, W. G. (2004). How to interpret changes in an athletic performance test. . *Sportscience, 8*, 1-7
Hopkins, W. G. (2005). Competitive performance of elite track and field athletes: Variability and smallest worthwhile enhancements. *Sportscience, 9*, 17-20
Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance, 4*, 461-473
Krzysztof, M., & Mero, A. (2013). A kinematic anlaysis of three best 100 m performances ever. Journal of Human Kinetics, 36, 149-160. doi: 10.2478/hukin-2013-0015
Lucia, A., Moran, M., Zihong, H., & Ruiz, J. R. (2010). Elite Athletes: Are the genes the champions? *International Journal of Sports Physiology and Performance, 5*, 98-102
Mac'kala, K. (2007). Optimisation of performance through kinematic analysis of the different phases of the 100 metres. *New Studies in Athletics, 22*, 7-16
MacArthur, D. G., & North, K. N. (2004). A gene for speed? The evolution and function of a-actinin-3. *BioEssays, 26*, 786-795
Mann, R. V. (2013). *The mechanics of sprinting and hurdling* (2013 ed.).
Milanese, C., Bertucco, M., & Zancanaro, C. (2014). The effects of three different rear knee angles on kinematics in the sprint start. *Biology of Sport, 31*(3), 209-215. doi: 10.5604/20831862.1111848
Missitzi, J., Geladas, N., & Klissouras, V. (2004). Heritability in Neuromuscular Coordination: Implications for Motor Control Strategies. *American College of Sports Medicine, 36*(2), 233-240
Morin, J. B., Edoudard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor in sprint performance. *Medicine & Science in Sports & Exercise, 43*(9), 1680-1688. doi: 10.1249/MSS.0b013c318216ea37
Nagahara, R., Naito, H., Morin, J. B., & Zushi, K. (2014). Association of acceleration with spatiotemporal variables in maximal sprinting. *International Journal of Sports Medicine, 35*, 755-761. doi: 10.1055/s-0033-1363252
Parker, R. I., Vannest, K. J., Davis, J. L., & Sauber, S. B. (2011). Combining nonoverlap and trend for single-case research: Tau-U. *Behavior Therapy, 42*, 284-299
Rabita, G., Dorel, S., Slawinski, J., Saez-de-Villarreal, E., Couturier, A., Samozino, P., & Morin, J. B. (2015). Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. *Scandinavian Journal of Medicine and Science in Sports, 25*(5), 583-594. doi: 10.1111/sms.12389
Rakap, S. (2015). Effect sizes as result interpretation aids in single-subject experimental research:

description and application of four nonoverlap methods. *British Journal of Special Education, 42*(1), 11-33

Ross, A., Leveritt, M., & Riek, S. (2001). Neural influences on sprint running. *Sports Med, 31*(6), 409-425

Rumpf, M. C., Cronin, J. B., & Schneider, C. (2014). Effect of different training methods on sprint times in recreational and athletic males. *Journal of Austrailian Strength and Conditioning, 22*(4), 62-73

Scott, R. A., Irving, R., Irwin, L., Morrison, E., Charlton, V., Austin, K., . . . Pitsiladis, Y. P. (2009). ACTN3 and ACE gentotypes in elite Jamaican and US sprinters. *Medicine & Science in Sports & Exercise*. doi: 10.1249/MSS.0b013e3181ae2bc0

Seitz, L. B., Reyes, A., Tran, T. T., Villarreal, E., & Haff, G. G. (2014). Increases in lower-body strength transfer positively to sprint performance: A systematic review with meta-analysis. *Sports Med, 44*, 1693-1702

Sides, D. L. (2014). *Kinematics and kinetics of maximal velocity sprinting and specificity of training in elite athletes.* (Doctor of Philosophy), University of Salford.

Stone, M. H., Sanborn, K., O'Bryant, H. S., Hartman, M., Stone, M. E., Proulx, C., . . . Hruby, J. (2003). Maximum strength-power-performance realtionships in collegiate throwers. Journal of Strength and Conditioning Research, *17*(4), 739-745

Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and practice of resistance training*: Human Kinetics.

Van Cutsem, M., Duchateau, J., & Hainaut, K. (1998). Changes in single motor unite behaviour contribute to the increase in contraction speed after dynamic training in humans. *Journal of Physiology, 513*(1), 295-305

Van Ingen Schenau, G. J., Koning, J. J., & de Groot, G. (1994). Optimisation of sprinting performance in running, cycling and speed skating. *Sports Med, 17*(4), 259-275

Vannest, K. J., Parker, R. I., Gonen, O., & Adiguzel, T. (2016). Sing Case Research: web beased calculators for SCR analysis.

Verhoshansky, Y., & Siff, M. (2009). *Supertraining sixth edition-Expanded version*. Ultimate Athlete Concepts.

Volkov, N. I., & Lapin, V. I. (1979). Analysis of the velocity curve in sprint running. *Med Sci Sports 17*, 332-337

Wang, G., Padmanabhan, S., Wolfarth, B., Fuku, N., Lucia, A., Ahmetov, I. I., . . . Pitsiladis, Y. (2013). Genomics of Elite Sporting Performance: What little We Know and Necessary Advances. *Advances in Genetics, 84*, 124-143. doi: 10.1016/B978-0-12-407703-4.00004-9

Weyand, P. G., Lee, C. S., Martinez-Ruiz, R., Bundle, M. W., Bellizzi, M. J., & Wright, S. (1999). High-speed running performance is largely unaffected by hypoxic reductions in aerobic power. *Journal of Applied Physiology, 86*(6), 2059-2064

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology*(89), 1991-1999

CHAPTER 4

SUMMARY AND FUTURE INVESTIGATIONS

The primary purpose of this thesis was to observe changes in sprint velocity, ground contact time, and peak force demonstrated by a competitive sprinter following an integrated approach to speed development and strength training. A secondary purpose was to provide coaches with a detailed synergistic approach to speed and strength training, termed Seamless Sequential Integration.

Observations in sprint velocity and peak isometric force demonstrated practical and statistically significant enhancements. Performance improvements were thought to be a product of increases in strength or ability to produce force resulting from a specialized sequence of training similar to Harris et al. (2000). Previously shown to be highly correlated with strength (Taber et al., 2016), the ability to produce force quickly (RFD) is a foundational element in sprinting performance (Clark & Weyand, 2014; Rabita et al., 2015).

While heightened physical abilities will enhance athletes' capacity to exert force, this by itself does not ensure improvements in technical movements. Thus, Seamless Sequential Integration (SSI) places emphasis on developing skilled movement and works to refine movement prowess with progressive physiological adaptations over time. Recently found, a dichotomy between elite and sub-elite sprinters, Rabita et al. (2015) highlight the importance of orientation of force. Demonstrating body segment positioning dictates force application, Kugler and Jansen (2010) clarify orientation of force is a function of athletes' ability to comprehend, replicate, and achieve desirable positions. Therefore, SSI serves to construct a curriculum to: enhance awareness and achievement of positions, orient forces accordingly, realize higher sprint velocities, generate a speed reserve, and delay speed decay. In this analysis the sprinter was able to attain higher and more consistent velocities, leading the authors to postulate body positions and force orientation improved over the course of the analysis.

While there was no practical increase in isometric force until the last time point, there were significant improvements in sprinting velocity as early as testing time point three. This may be due to the athletes increased ability to direct forces into the ground in a more advantageous manner, resulting from a speed development approach geared toward enhancing accelerative abilities. Evidence from Plautz, Milliken, and Nudo (2000) suggest motor learning is a prerequisite related to motor performances. Jensen, Marstrand, and Nielsen (2005) suggest strength training with simultaneous motor learning can lead to improved muscular coordination. When combined coordination of skillful movements and enhanced physical abilities allow for greater sprint performances, as force generation is partially determined by muscular coordination (Carroll, Riek, & Carson, 2001). Increases in sprint speed seen at later time points may be attributed to a realization of explosive ability. Early results may be justified by learning and refinement of a skill and later results substantiate increased explosive ability through which skill was bolstered further.

Results coincide with a common phenomenon seen in youth and inexperienced athletes where early adaptations are believed to be rooted in neural adaptations and later adaptations are understood as manifestations of physical maturation (Myer, Lloyd, Brent, & Faigenbaum, 2013; Verhoshansky & Siff, 2009). Evidence suggests learning: creates more efficient movements, requires less neural activation, and generates more force through a multitude of different mechanisms (Carroll, Riek, & Carson, 2001).

While all movement originates in the central nervous system, a learning rich environment serves to accelerate communication from the central nervous system to the muscular system.

Movement may only occur after an action potential reaches the neuromuscular junction, eventually causing cross-bridges within the muscle to be formed and force generated. Subsequently, after this potential reaches the muscle, it is the physiological profile (muscle fiber type, fiber distribution, pennation angle, fascicle length, etc.) that determines how quickly force is produced. Therefore, the emphasis on learning a skill supports quicker neurological communication, while sequenced weight training allows heightened physiology to deliver force at a greater rate after the signal arrives at the muscle. The findings of this inquiry support the use of SSI with an elite-level sprinter.

Enhancing sprinting speed should therefore focus on skillful force application where early exposures are meant to teach the athlete how to position his or her body to optimally transmit forces into the ground. Simultaneously, the coach will be urged to enhance the physical abilities of the athlete through strength training. If the athlete is taught how to apply forces properly while simultaneously improving physical abilities, these two facets are believed to compound on each other and promote additional enhancements. Approaches focusing on segregated training means may cease to provide long term adaptations after neural adaptations have taken place. An integrated approach over the course of a career may yield gains for long durations as physical abilities will supplant the athletes technically sound skillset.

Future investigations should use similar designs and training regimens but employ them over longer time periods. Observations past 20m would be optimal and although kinematic data is useful, kinetic data collected would be more beneficial.

REFERENCES

Ae, M., Ito, A., & Suzuki, M. (1992). The men's 100 metres. *IAAF, 7*(1), 47-52.

Banich, M. T. (2004). *Cognitive neuroscience and neurophysiology-Second Edition*. Houghton Mifflin Company.

Barany, M. (1967). ATPase Activity of Myosin Correlated with Speed of Muscle Shortening. *J Gen Physiol, 50*(6), 197-218.

Bazyler, C. D. (2016). *Tapering for strength-power individual event and team sport athletes*.

Bellon, C. (2016). *The relationship between strength, power, and sprint acceleration in division I men's soccer players*.

Billat, L. V. (2001). Interval training for performance: A scientific and empirical practice. *Sports Medicine, 31*(1), 13-31.

Bingham, G. E., Wagle, J. P., Fiolo, N., & DeWeese, B. H. (2016). *An elite athlete's initial uphill battle*. Paper presented at the 11th Annual Coaches and Sport Science College, Johnson City, TN.

Bodine, S. C., Roy, R. R., Meadows, D. A., Zernicke, R. F., Sacks, R. D., Fournier, M., & Edgerton, V. R. (1982). Architectural, histochemical, and contractile characteristics of a unique biarticular muscle: the cat semitendinosus. *Journal of Neurophysiology, 48*(1), 192-201.

Bolger, R., Lyons, M., Harrison, A. J., & Kenny, I. C. (2015). Sprinting performance and resistance-based training interventions: A systematic review. *Journal of Strength and Conditioning Research, 29*(4), 1146-1156.

Bompa, T. O., & Haff, G. G. (2009). *Periodization-Theory and methodology of training-5th Edition*.

Brazil, A., Exell, T., Wilson, C., Willwacher, S., Bezodis, I., & Irwin, G. (2016). Lower limb joint kinetics in the starting blocks and first stance in athletic sprinting. *Journal of Sport Sciences*. doi:10.1080/02640414.2016.1227465

Brazil, A., Irwin, G., Exell, T., Bezodis, I., Wilson, C., & Willwacher, S. (2015). *Magnitude and technical characteristics of external force production in the starting blocks: Relationship with performance*. Paper presented at the 33rd International Conference on Biomechanics in Sports, Poiters, France.

Bret, C., Rahmani, A., Dufour, A. B., Messonier, L., & Lacour, J. R. (2002). Leg strength and stiffness as ability factors in 100 m sprint running. *Journal of Sports Medicine and Physical Fitness, 42*, 274-281.

Bruggeman, G. P., & Glad, B. (1990). Time anlaysis of the sprint events. Scientific research project at the games of the XXIVth Olympiad- Seoul 1988: final report. *New Studies in Athletics, 1*, 11-89.

Buechner, M. (2015). *Gait intervention for improvements in human top speed running.* University of Montana.

Caine, D. J., & Broekhoff, J. (1987). Maturity assessment: A viable preventive measure against physical and psychological insult to the young athlete? *The Physician and Sportsmedicine, 15*(3), 67-80.

Carroll, T. J., Riek, S., & Carson, R. G. (2001). Neuarl adaptations to resistance training. *Sports Med, 31*(12), 829-840.

Chiu, L. Z. F., & Schilling, B. K. (2005). A primer on weightlifting from sport to sports training. *Strength and Conditioning Journal, 27*(1), 42-48.

Chu, D. C. (1983). Plyometrics: The link between strength and speed. *NSCA Journal, 5*(2), 20-21.

Clark, K. P., & Weyand, P. G. (2014). Are running speeds maximized with simple-spring stance mechanics? *Journal of Applied Physiology, 117*, 604-615. doi:10.1152/japplephysiol.00174.2014

Clark, K. P., & Weyand, P. G. (2015). Sprint running research speeds up: A first loook at the mechanics of elite acceleration. *Scandinavian Journal of Medicine and Science in Sports, 25*, 581-582. doi:10.1111/sms.12520

Clement, D. B., & Taunton, J. E. (1981). A guide to the prevention of running injuries. *Austrailian Family Physician, 10*(3), 163-164.

Coffey, V. G., & Hawley, J. A. (2007). The molecular bases of training adaptation. *Sports Med, 37*(9), 737-763.

Coh, M., Jost, B., Skof, B., Tomazin, K., & Dolenec, A. (1998). Kinematic and kinetic parameters of the sprint start and start acceleration model of top sprinters. *Gymnica, 28*, 33-42.

Coh, M., & Tomazin, K. (2006). Kinematic analysis of hte spritn start and acceleration from the blocks. *New Studies in Athletics, 3*, 23-33.

Coh, M., Zvan, M., Velickovska, L. A., Zivkovic, V., & Gontarev, S. (2016). Biodynamical factors of running speed development. *Research in Physical Education, Sport and Health, 5*(1), 17-22.

Coh, M., Zvan, M., Velickovska, L. A., Zivkovic, V., & Gontarev, S. (2016). Biodynamical factors of running speed development. *Research in Physical Education, Sport and Health, 5*(1), 17-22.

Coker, C. A. (2013). *Motor learning & control for practitioners*: Holcomb Hathaway, Publishers, Inc.

Comfort, P., Allen, M., & Graham-Smith, G. (2011). Kinetic comparisons during variations of the power clean. *Journal of Strength and Conditioning Research, 25*(12), 3269-3273.

Comfort, P., Allen, M., & Graham-Smith, G. (2011). Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *Journal of Strength and Conditioning Research, 25*(5), 1235-1239.

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power. Part 1-Biological basis of maximal power production. *Sports Med, 41*(1), 17-38.

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power-Part 2- Training considerations for improving maximal power production. *Sports Medicine, 41*(2), 125-146.

Costill, D. L., Daniels, J., Evans, W., Fink, W., Krahenbuhl, G., & Saltin, B. (1976). Skeletal muscle enzymes and fiber composition in male and female track athletes. *J Appl Physiol, 40*(2), 149-1954.

Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research, 19*(2), 349-357.

Cross, M. R. (2016). *Force-velocity profiling in sled-resisted sprint running: Determining the optimal conditions for maximazing power.* Auckland University.

De Villarreal, E. S., Requena, B., Izquierdo, M., & Gonzalez-Badillo, J. J. (2013). Enhancing sprint and strength performance: Combined versus maximal power, traditional heavy-resistance and plyometric training. *Journal of science and medicine in sport, 16*, 146-150. doi:10.1016/j.jsams.2012.05.007

Debaere, S., Delecluse, C., Aerenhouts, D., Hagman, F., & Jonkers, I. (2013). From block clearance to sprint running: Characterisitcs underlying an effective transition. *Journal of*

Sport Sciences, 31(2), 137-149. doi:10.1080/02640414.2012.722225

Debaere, S., Jonkers, I., & Delecluse, C. (2013). The contribution of step characteristics to sprint running performance in high-level male and female atheltes. *Journal of Strength and Conditioning Research, 27*(1), 116-124.

Delecluse, C. (1997). Influence of strength training on sprint running performance. *Sport Med, 24*(3), 147-156.

DeWeese, B. H., Bellon, C., Magrum, E. D., Taber, C., & Suchomel, T. (2015). Strengthening the springs-Improving sprinting performance via strength training. *Techniques, 9*.

DeWeese, B. H., Gray, H. S., Sams, M. L., Scruggs, S. K., & Serrano, A. J. (2013). Revising the definition of periodization: Merging historical principles with modern concern. *Olympic Coach, 24*(1), 5-19.

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015). The training process: Planning for strength-power training in track and field. Part 1: Theoretical aspects. *Journal of Sport and Health Science, 4*, 308-317. doi:10.1016/j.jshs.2015.07.003

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

DeWeese, B. H., Sams, M., & Serrano, A. (2014). Sliding toward sochi-part I: A review of programming tactics used during the 2010-2014 quandrennial. *NSCA Coach, 1*(3), 30-43.

DeWeese, B. H., Sams, M., & Serrano, A. (2014). Sliding towards sochi-part II: A review of programming tactics used during the 2010-2014 quadrennial. *NSCA Coach, 1*(4), 4-7.

DeWeese, B. H., Serrano, A., Scruggs, S. K., & Burton, J. D. (2013). The midthigh pull: Proper application and progressions of a weightlifting movement derivative. *Strength and*

Conditioning Journal, 35(6), 54-58.

DeWeese, B. H., Williams, J. H., Bellon, C., & Sams, M. L. (2015). The Nature of Speed. *Techniques 8,* 10-22.

Dick, F. W. (1989). Development of maximum sprinting speed. *Track Coach, 109,* 3475-3480.

Dick, F. W. (2005). NSA Interview. *IAAF, 20*(4), 19-22.

Dickinson, M. H., Farley, C. T., Full, R. J., Koehl, M. A. R., Kram, R., & Lehman, S. (2000). How animals move: An integrative view. *Science, 288*, 100-106. doi:10.1126/science.288.5463.100

Edgerton, V. R., Roy, R. R., Gregor, R. J., & Rugg, S. (1986). Morphological basis of skeletal muscle power output.

Enoka, R. M. (1995). Morphological features and activation patterns of motor units. *Journal of Clinical Neurophysiology, 12*(6), 538-559.

Eynon, N., Hanson, E. D., Lucia, A., Houweling, P. J., Garton, F., North, K. N., & Bishop, D. J. (2013). Genes for elite power and sprint performance: ACTN3 leads the way. *Sports Med, 43*, 803-817. doi:DOI 10.1007/s40279-013-0059-4

Francis, C. (1992). *The charlie francis training system*.

Frost, H. M. (1994). Wolff's law and bone's structural adaptations to mechanical usage: an overview for clinicians. *The Angle Orthodontist, 64*(3), 175-188.

Gottschall, J. S., & Kram, R. (2005). Ground reaction forces during downhill and uphill running. *Journal of Biomechanics, 38*, 445-452.

Grimston, S. K., Nigg, B. M., Fisher, V., & Ajemian, S. V. (1994). External loads throughout a 45 minute run in stress fracture and non-stress fracture runners. *Journal of Biomechanics, 27*(6), 668.

Haff, G. G., & Nimphius, S. (2012). Training principles for power. *Strength and Conditioning Journal, 34*(6), 2-12.

Haff, G. G., & Stone, M. H. (2015). Methods of developing power with special reference to football players. *Strength and Conditioning Journal, 37*(6), 2-16.

Halperin, I., Hughes, S., & Chapman, D. W. (2016). Physiological profile of a professional boxer preparing for Title bout: A case study. *Journal of Sport Sciences*, 1-8. doi:10.1080/02640414.2016.1143110

Hamil, B. P. (1994). Relative safety of weightlifitng and weight training. *Journal of Strength and Conditioning Research, 8*(1), 53-57.

Harland, M. J., & Steele, J. (1997). Biomechanics of the sprint start. *Sports Med, 23*(1), 11-20.

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. *Journal of Strength and Conditioning Research, 14*(1), 14-20.

Hedrick, A., & Wada, H. (2008). Weightlifting movements: Do the benefits outweight the risks? *Strength and Conditioning Journal, 30*(6), 26-34.

Hopkins, W. G. (2004). How to interpret changes in an athletic performance test. . *Sportscience, 8*, 1-7.

Hopkins, W. G. (2005). Competitive performance of elite track and field athletes: Variability and smallest worthwhile enhancements. *Sportscience, 9*, 17-20.

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? *Journal of Strength and Conditioning Research, 22*(2), 412-418.

Hori, N., Newton, R. U., Kazunori, N., & Stone, M. H. (2005). Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength and Conditioning Journal, 27*(4), 50-55.

Hunter, J. P., Marshall, R. N., & McNair, P. J. (2005). Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *Journal of Applied Biomechanics, 21*, 31-43.

Huxley, A. F., & Niedergerke, R. (1954). Structural changes in muscle during contraction; interference microscopy of living muscle fibers. *Nature, 173*(4412), 971-973.

Huxley, H. E. (1958). The contraction of muscle. *Scientific American, 199*(5), 67-72.

Huxley, H. E., & Hanson, J. (1954). Changes in the cross-striations of muscle during contraction and stretch and their structural interpretation. *Nature, 173*(4412), 973-976.

Issurin, V. B. (2008). Block periodization versus traditional training theory: a review. *Journal of Sports Medicine and Physical Fitness, 48*, 65-75.

Issurin, V. B. (2010). New horizons for the methodology and physiology of trainin periodization. *Sports Medicine, 40*(3), 189-206.

Jefferys, I., & Moody, J. (2016). *Strength and Conditioning for Sports Performance*. London and New York: Routledge.

Jensen, J. L., Marstrand, P. C. D., & Nielsen, J. B. (2005). Motor skill training and strength training are associated with different plastic changes in the central nervous system. *Journal of Applied Physiology, 99*, 1558-1568. doi:10.1152/japplphysiol.01408.2004.

Johnson, M. D., & Buckley, J. G. (2001). Muscle power patterns in the mid-acceleration phase of sprinting. *Journal of Sports Sciences, 19*, 263-272.

Judge, L. W. (2007). Training program for the collegiate throwers. *Strength and Conditioning*

Journal, 29(5), 42-54.

Kenney, W. L., Wilmore, J. H., & Costill, D. L. (2012). *Physiology of sport and exercise-Fifth Edition*. Human Kinetics.

Kinugasa, T. (2013). The application of single-case research designs to study elite athletes' conditioning: An update. *Journal of Applied Sport Psychology, 25*(25), 157-166. doi:10.1080/10413200.2012.709578

Kinugasa, T., Cerin, E., & Hooper, S. (2004). Single-subject research designs and data anlayses for assessing elite athletes' conditioning. *Sports Medicine, 34*(15), 1035-1050.

Kraska, J. M., Ramsey, M. W., Haff, G. G., Fethke, N., Sands, W. A., Stone, M. E., & Stone, M. H. (2009). Relationship between strength characteristics and unweighted and weighted vertical jump height. *International Journal of Sports Physiology and Performance, 4*, 461-473.

Krzysztof, M., & Mero, A. (2013). A kinematic anlaysis of three best 100 m performances ever. *Journal of Human Kinetics, 36*, 149-160. doi:10.2478/hukin-2013-0015

Kugler, F., & Janshen, L. (2010). Body position determines propulsive forces in accelerated running. *Journal of Biomechanics, 43*, 343-348.

Loturco, I., Pereira, L. A., Kobal, R., Zanetti, V., Kitamura, K., Cal Abad, C. C., & Nakamura, F. Y. (2015). Transference effect of vertical and horizontal plyometrics on sprint performance of high-level U-20 soccer players. *Journal of Sports Sciences*. doi:10.1080/02640414.2015.1081394

Lucia, A., Moran, M., Zihong, H., & Ruiz, J. R. (2010). Elite Athletes: Are the genes the champions? *International Journal of Sports Physiology and Performance, 5*, 98-102.

Mac'kala, K. (2007). Optimisation of performance through kinematic analysis of the different phases of the 100 metres. *New Studies in Athletics, 22*, 7-16.

MacArthur, D. G., & North, K. N. (2004). A gene for speed? The evolution and function of a-actinin-3. *BioEssays, 26*, 786-795.

Malisoux, L., Francaux, M., Nielens, H., & Theisen, D. (2005). Stretch-shortening cycle exercises: an effective training paradigm to enhance power output of human single muscle fibers. *J Appl Physiol, 100*, 771-779. doi:10.1152/japplphysiol.01027.2005.

Maloney, S. J., Turner, A. N., & Fletcher, I. M. (2014). Ballistic exercise as a pre-activation stimulus: A review of the literature and practical applications. *Sports Medicine, 44*, 1347-1359. doi:10.1007/s40279-014-0214-6

Mann, R. V. (2013). *The mechanics of sprinting and hurdling* (2013 ed.).

Markovic, G., & Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine, 40*(10), 859-895.

Maulder, P. S., Bradshaw, E. J., & Keogh, J. (2006). Jump kinetic determinatns of sprint acceleration performance from starting *Journal of Sports Science and Medicine, 5*, 359-366.

Maulder, P. S., Bradshaw, E. J., & Keogh, J. W. L. (2008). Kinematic alterations due to different loading schemes in early acceleration sprint performance from starting blocks. *Journal of Strength and Conditioning Research, 22*(6), 1992-2002.

McBride, J. M., Triplett-McBride, T., Davie, A., & Newton, R. U. (1999). A comparison of strength and power characteristics betwen power lifters, olympic lifters, and sprinters. *Journal of Strength and Conditioning Research, 13*(1), 58-66.

McCann. (2008). At the Olympics, everything is a performance issue. *International Journal of Sport and Exercise Psychology, 6*(3), 267-276. doi:10.1080/1612197x.2008.9671871

Mero, A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of sprint running. *Sports Medicine, 13*(6), 376-392.

Mero, A., Komi, P. V., & Gregor, R. J. (1992). Biomechanics of sprint running: A review. *Sports Medicine, 13*(6), 376-392.

Mero, A., Luhtanen, P., & Komi, P. V. (1983). A biomechanical study of the sprint start. *Scandinavian Journal of Medicine and Science in Sports, 5*(1), 20-28.

Methenitis, S., Terzis, G., Zaras, N., Stasinaki, A. N., & Karandreas, N. (2016). Intramuscular fiber conduction velocity, isometric force and explosive performance. *Journal of Human Kinetics, 51*, 93-101. doi:10.1515/hukin-2015-0174

Milanese, C., Bertucco, M., & Zancanaro, C. (2014). The effects of three different rear knee angles on kinematics in the sprint start. *Biology of Sport, 31*(3), 209-215. doi:10.5604/20831862.1111848

Miller, R. H., Umberger, B. R., & Caldwell, G. E. (2012). Limitations to maximum sprinting speed imposed by muscle mechanical properties. *Journal of Biomechanics, 45*, 1092-1097. doi:10.1016/j.jbiomech.2011.04.040

Missitzi, J., Geladas, N., & Klissouras, V. (2004). Heritability in Neuromuscular Coordination: Implications for Motor Control Strategies. *American College of Sports Medicine, 36*(2), 233-240.

Moir, G., Sanders, R., Button, C., & Glaister, M. (2007). The effect of periodized resistance training on accelerative sprint performance. *Sports Biomechanics, 6*(3), 285-300. doi:10.1080/14763140701489793

Morin, J. B., Bourdin, M., Edouard, P., Peyrot, N., Samozino, P., & Lacour, J. (2012). Mechanical determinants of 100-m sprint running performance. *European Journal of*

Applied Physiology, 112(11), 3921-3930. doi:10.1007/s00421-012-2379-8

Morin, J. B., Edoudard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor in sprint performance. *Medicine & Science in Sports & Exercise, 43*(9), 1680-1688. doi:10.1249/MSS.0b013c318216ea37

Mrowczynski, W., & Lochynski, D. (2014). Physiological adaptations of motor units to endurance and strength training. *Trends in Sport Sciences, 3*(21), 129-134.

Mujika, I., & Padilla, S. (2003). Scientific bases for precompetition tapering strategies. *Physical fitness and performance, 35*(7), 1182-1187. doi:10.1249/01.MSS.0000074448.73931.11

Myer, G. D., Lloyd, R. S., Brent, J. L., & Faigenbaum, A. D. (2013). How young is "Too Young" to start training? *ACSM's Health & Fitness Journal, 17*(5), 14-23.

Nagahara, R., Mizutani, M., & Matsuo, A. (2016). *Ground reaction force of the first transition during accelerated sprinting: A pilot study*. Paper presented at the 34th International Conference on Biomechanics in Sport, Tsukuba, Japan.

Nagahara, R., Naito, H., Morin, J. B., & Zushi, K. (2014). Association of acceleration with spatiotemporal variables in maximal sprinting. *International Journal of Sports Medicine, 35*, 755-761. doi:10.1055/s-0033-1363252

Nyitrai, M., Rossi, R., Adamek, N., Pellegrino, M. A., Bottinelli, R., & Geeves, M. A. (2006). What limits the velocity of fast-skeletal muscle contraction in mammals? *Journal of Molecular Biology, 355*, 432-442.

Padulo, J., Mignogna, P., Mignardi, S., Tonni, F., & Ottavio, S. D. (2012). Effect of different pushing speeds on bench press. *International Journal of Sports Medicine, 33*(05), 376-380. doi:10.1055/s-0031-1299702

Parker, R. I., Vannest, K. J., Davis, J. L., & Sauber, S. B. (2011). Combining nonoverlap and trend for single-case research: Tau-U. *Behavior Therapy, 42*, 284-299.

Penailillo, L., Espildora, F., Jannas-Vela, S., Mujika, I., & Zbinden-Foneca, H. (2016). Muscle strength and speed performance in youth soccer players. *Journal of Human Kinetics, 50*, 203-210.

Pistilli, E. E., Kaminsky, D. E., Totten, L. M., & Miller, D. R. (2008). Incorporating one week of planned overreaching into the training program of weightlifters. *Strength and Conditioning Journal, 30*(6), 39-44.

Plautz, E. J., Milliken, G. W., & Nudo, R. J. (2000). Effects of repetitive motor training on movement representations in adult squirrel monkeys: role of use versus learning. *Neurobiology of Learning and Memory, 74*, 27-55. doi:10.1006/nlme.1999.3934

Plisk, S., & Stone, M. (2003). Periodization Strategies. *Strength and Conditioning Journal, 25*(6), 19-37.

Rabita, G., Dorel, S., Slawinski, J., Saez-de-Villarreal, E., Couturier, A., Samozino, P., & Morin, J. B. (2015). Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. *Scandinavian Journal of Medicine and Science in Sports, 25*(5), 583-594. doi:10.1111/sms.12389

Rakap, S. (2015). Effect sizes as result interpretation aids in single-subject experimental research: description and application of four nonoverlap methods. *British Journal of Special Education, 42*(1), 11-33.

Ross, A., Leveritt, M., & Riek, S. (2001). Neural influences on sprint running. *Sports Med, 31*(6), 409-425.

Rumpf, M. C., Cronin, J. B., & Schneider, C. (2014). Effect of different training methods on sprint times in recreational and athletic males. *Journal of Austrailian Strength and*

Conditioning, 22(4), 62-73.

Rumpf, M. C., Lockie, R. G., Cronin, J. B., & Jalilvand, F. (2016). Effect of different sprint training methods on sprint performance over various distances: A brief review. *Journal of Strength and Conditioning Research, 30*(6), 1767-1785.

Saladin, K. S. (2010). *Anatomy & Physiology. The unity of form and function*: McGraw-Hill.

Sale, D. G. (1988). Neural adaptation to resistance training. *Medicine & Science in Sports & Exercise, 20*(5), S135-S145.

Salo, A. I. T., Gayen, M., Patterson, J., & Wilson, C. (2016). *Should athletes use their stronger leg on teh front block during the sprint start?* Paper presented at the 34th International Conference on Biomechanics in Sports, Tsukuba, Japan.

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength and Conditioning Research, 24*(10), 2857-2872.

Scott, R. A., Irving, R., Irwin, L., Morrison, E., Charlton, V., Austin, K., . . . Pitsiladis, Y. P. (2009). ACTN3 and ACE gentotypes in elite Jamaican and US sprinters. *Medicine & Science in Sports & Exercise*. doi:10.1249/MSS.0b013e3181ae2bc0

Scott, W., Stevens, J., & Binder-Macleod, S. A. (2001). Human skeletal muscle fiber type classification. *Physical Therapy, 81*(11), 1810-1816.

Seitz, L. B., Reyes, A., Tran, T. T., Villarreal, E., & Haff, G. G. (2014). Increases in lower-body strength transfer positively to sprint performance: A systematic review with meta-analysis. *Sports Med, 44*, 1693-1702.

Semmler, J. G. (2002). Motor unite synchronization and neuromuscular performance. *Exercise and Sports Science Review, 30*(1), 8-14.

Shepherd, J. (2008). Conditioning sprint accleration: Recent research. *The Coach*.

Shoepe, T. C., Stelzer, J. E., Garner, D. P., & Widrick, J. J. (2003). Functional adaptability of muscle fibers to long-term resistance exercise. *Med Sci Sports Exerc, 35*(6), 944-951.

Sides, D. L. (2014). *Kinematics and kinetics of maximal velocity sprinting and specificity of training in elite athletes.* (Doctor of Philosophy), University of Salford.

Siemankowski, R. F., Wiseman, M. O., & White, H. D. (1985). ADP dissociation from actomyosin subfragment 1 is sufficiently slow to limit the unloaded shortening volecity in vertebrate muscle. *Proc Natl Acad Sci USA, 82*(3), 658-662.

Slawinski, J., Bonnefoy, A., Leveque, J. M., Ontanon, G., Riquet, A., Dumas, R., & Cheze, L. (2010). Kinematic and kinetic comparisons of elite and well-trained sprinters during sprint start. *Journal of Strength and Conditioning Research, 24*(4), 896-905.

Slawinski, J., Dorel, S., Hug, F., Couturier, A., Fournel, V., Morin, J. B., & Hanon, C. (2008). Elite long sprint running: A comparison between incline and level training sessions. *Medicine & Science in Sports & Exercise, 40*(6), 1155-1162. doi:10.1249/MSS.0b013e3181676681

Slawinski, J., Termoz, N., Rabita, G., Guilhem, G., Dorel, S., Morin, J. B., & Samozino, P. (2015). How 100-m event anlayses improve our understanding of world-class men's and women's sprint performance. *Scandinavian Journal of Medicine and Science in Sports*, 1-10. doi:10.111/sms.12627

Sleivert, G., & Taingahue, M. (2004). The relationship between maximal jump-squat power and sprint acceleration in athletes. *Eur J Appl Physiol, 91*, 46-52. doi:10.1007/s00421-003-0941-0

Spinks, C. D., Murphy, A. J., Spinks, W. L., & Lockie, R. G. (2007). The effects of resisted sprint training on acceleration performance and kinematics in soccer, rugby union, and

Austrailian football players. *Journal of Strength and Conditioning Research, 21*(1), 77-85.

Stone, M. (2015). Maximum strength/explosive strength/power production. . East Tennessee State University, Johnson City, TN.

Stone, M. (2015). Maximum Strength/Explosive Strength/Power Production. . Johnson City, TN.

Stone, M., Moir, G., Glaister, M., & Sanders, R. (2002). How much strength is necessary? *Physical Therapy in Sport, 3*, 88-96. doi:10.1054/ptsp.2001.0102

Stone, M. H., Byrd, R., Tew, J., & Wood, M. (1980). Relationship between anaerobic power and olympic weightlifting performance. *Journal of Sports Medicine and Physical Fitness, 20*(1), 99-102.

Stone, M. H., O'Bryant, H. S., & Garhammer, J. (1981). A hypothetical model for strength training. *Journal of Sports Medicine and Physical Fitness, 21*(4), 342-351.

Stone, M. H., O'Bryant, H. S., Garhammer, J., McMillan, J., & Rozenek, R. (1982). A theoretical model of strength training. *NSCA Journal, 4*(4), 36-39.

Stone, M. H., Sanborn, K., O'Bryant, H. S., Hartman, M., Stone, M. E., Proulx, C., . . . Hruby, J. (2003). Maximum strength-power-performance realtionships in collegiate throwers. *Journal of Strength and Conditioning Research, 17*(4), 739-745.

Stone, M. H., Sands, W. A., Pierce, R. C., Newton, R. U., Haff, G. G., & Carlock, J. (2006). Maximum strength and strength training-A relationship to endurance. *Strength and Conditioning Journal, 28*(3), 44-53.

Stone, M. H., Stone, M., & Sands, W. A. (2007). *Principles and practice of resistance training*: Human Kinetics.

Suchomel, T., Comfort, P., & Stone, M. H. (2015). Weightlifting pulling derivatives: Rationale for implementation and application. *Sports Medicine, 45*(823). doi:10.1007/s40279-015-

0314-y

Suchomel, T., Nimphius, S., & Stone, M. H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine, 46*(10), 1419-1449.

Suzuki, M., Umeda, T., Nakaji, S., Shimoyama, T., Mashiko, T., & Sugawara, K. (2004). Effect of incorporating low intensity exercise into the recovery period after a rugby match. *British Journal of Sports Medicine, 38*, 436-440. doi:10.1136/bjsm.2002.004309

Taber, C., Bellon, C., Abbott, H., & Bingham, G. E. (2016). Roles of maximal strength and rate of force development in maximizing muscular power. *Strength and Conditioning Journal, 38*(1), 71-78.

Tellez, T., & Doolittle, D. (1984). Sprinting from start to finish. *Track Technique, 88*, 2802-2805.

Thorstensson, A., Grimby, G., & Karlsson, J. (1976). Force-velocity relations and fiber composition in human knee extensor muscles. *J Appl Physiol, 40*(1), 12-16.

Tihanyi, J., Apor, P., & Fekete, G. (1982). Force-velocity-power characteristics and fiber composition in human knee extensor muscles. *Eur J Appl Physiol, 48*(331-343).

Trappe, S., Luden, N., Minchev, K., Raue, U., Jemiolo, B., & Trappe, T. A. (2015). Skeletal muscle signature of a champion sprint runner. *J Appl Physiol, 118*, 1460-1466.

Tricoli, V., Lamas, L., Carnevale, R., & Ugrinowitsch, C. (2005). Short-term effects on lower-body functional power development: Weightlifting vs. Vertical jump training programs. *Journal of Strength and Conditioning Research, 19*(2), 433-437.

Van Cutsem, M., Duchateau, J., & Hainaut, K. (1998). Changes in single motor unite behaviour contribute to the increase in contraction speed after dynamic training in humans. *Journal of Physiology, 513*(1), 295-305.

Van Ingen Schenau, G. J., Koning, J. J., & de Groot, G. (1994). Optimisation of sprinting performance in running, cycling and speed skating. *Sports Med, 17*(4), 259-275.

Vannest, K. J., Parker, R. I., Gonen, O., & Adiguzel, T. (2016). Sing Case Research: web beased calculators for SCR analysis. .

Verhoshansky, Y. (2006). *Special strength training-A practical manual for coaches*. Moscow.

Verhoshansky, Y., & Siff, M. (2009). *Supertraining sixth edition-Expanded version*. Ultimate Athlete Concepts.

Viru, A. (1995). *Adaptation in sports training*: CRC Press.

Viru, A., & Viru, M. (2001). *Biomechanical monitoring of sport training*: Human Kinetics.

Volkov, N. I., & Lapin, V. I. (1979). Analysis of the velocity curve in sprint running. *Med Sci Sports, 17*, 332-337.

Wang, G., Padmanabhan, S., Wolfarth, B., Fuku, N., Lucia, A., Ahmetov, I. I., . . . Pitsiladis, Y. (2013). Genomics of Elite Sporting Performance: What little We Know and Necessary Advances. *Advances in Genetics, 84*, 124-143. doi:10.1016/B978-0-12-407703-4.00004-9

Wessel, T., Haan, A., Laarse, W. J., & Jaspers, R. T. (2010). The muscle fiber type-fiber size paradox: hypertrophy or oxidative metabolism? *Eur J Appl Physiol, 110*, 665-694. doi:10.1007/s00421-010-1545-0

Weyand, P. G., Lee, C. S., Martinez-Ruiz, R., Bundle, M. W., Bellizzi, M. J., & Wright, S. (1999). High-speed running performance is largely unaffected by hypoxic reductions in aerobic power. *Journal of Applied Physiology, 86*(6), 2059-2064.

Weyand, P. G., Lin, J. E., & Bundle, M. W. (2006). Sprint performance-duration relationships are set by the fractional duration of external force application. *Am J Physiol Regul Integr Comp Physiol, 290*, 758-765. doi:10.1152/ajpregu.00562.2005

Weyand, P. G., Sandell, R. F., Prime, D. N. L., & Bundle, M. W. (2010). The biological limits to running speed are imposed from the ground up. *Journal of Applied Physiology, 108*, 950-961. doi:10.1152/japplphysiol.00947.2009

Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of Applied Physiology*(89), 1991-1999.

Widrick, J. J., Stelzer, J. E., Shoepe, T. C., & Garner, D. P. (2002). Functional properties of human muscle fibers after short-term reistance exercise training. *Am J Physiol Regul Integr Comp Physiol, 283*, R408-416.

Wilson, J. M., Marin, P. J., Rhea, M. R., Wilson, S. M. C., Loenneke, J. P., & Anderson, J. C. (2012). Concurrent training: A meta-analysis examining interference of aerobic and resistance exercises. *Journal of Strength and Conditioning Research, 26*(8), 2293-2307.

Young, M. (2009). *Development and application of an optimization model for elite level shot putting*.

Young, W., McLean, B., & Ardagna, J. (1995). Relationship between strength qualities and sprinting performance. *Journal of Sports Medicine and Physical Fitness, 35*(1), 13-19.

Yu, J., Sun, Y., Yang, C., Wang, D., Yin, K., Herzog, W., & Liu, Y. (2015). Biomechanical insights into differences between the mid-acceleration and maximum velocity phases of sprinting. *Journal of Strength and Conditioning Research, 30*(7), 1906-1916.

Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and practice of strength training* Human Kinetics.

APPENDICES

APPENDIX A: ETSU Institutional Review Board Approval

EAST TENNESSEE STATE
UNIVERSITY

Office for the Protection of Human Research Subjects • Box 70565 • Johnson City, Tennessee 37614-1707
Phone: (423) 439-6053 Fax: (423) 439-6060

IRB APPROVAL – Initial Expedited Review

October 5, 2016

Eric Magrum

Re: A look into the training and outcomes of an Elite level sprinter: A Case Study
IRB#: c0916.18sw
ORSPA #:

The following items were reviewed and approved by an expedited process:

- New protocol submission xForm, Pertinent literature, Eric Daniel Magrum VITA, Collection Sheet Sprints, Collection Sheet Iso-Pull

On **October 4, 2016**, a final approval was granted for a period not to exceed 12 months and will expire on **October 3, 2017**. The expedited approval of the study *and* requested changes will be reported to the convened board on the next agenda.

The study has been granted a Waiver or Alteration of Informed Consent under category 45 CFR 46.116(d).

The research involves no more than minimal risk to the participants as the study is only analysis of retrospectively collected data from monitoring that is located in the research repository and the athlete already gave consent to have his data put into the repository for research purposes. The waiver or alteration will not adversely affect the rights and welfare of the subjects as the study is only analysis of retrospectively collected data from monitoring that is located in the research repository and the athlete already gave consent to have his data put into the repository for research purposes.. The research could not practicably be carried out without the waiver or alteration as the PI does not have contact with the athlete and the athlete is no longer at ETSU. Providing participants additional pertinent information after participation is not appropriate as there is no information to share with the participant whose data will be analyzed.

Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.

Association for the Accreditation of Human Research Protection Programs, Inc.
Full AAHRPP Accreditation

Accredited Since December 2005

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,
Stacey Williams, Ph.D., Chair
ETSU Campus IRB

cc: Brad DeWeese

APPENDIX B: ETSU Informed Consent Document

PRINCIPAL INVESTIGATOR: Michael H. Stone

TITLE OF PROJECT: Sport Science Research Repository (Non ETSU Athletes)

INFORMED CONSENT DOCUMENT (ICD)

This Informed Consent will explain about being a participant in a research repository. It is important that you read this material carefully and then decide if you wish to be a volunteer.

What is a research repository?
A research repository is a database (data bank) that is a collection of information from the records of many individuals. The database is used to store data for future use. The databank includes codes that identify each person whose information is collected. If you decide to join this research repository, the repository may keep your athletic monitoring information and share it with researchers who study sports science.

What is the purpose of this repository?
Information in the Sports Science Research Repository will be used to help researchers learn more about the field of sports science, including sport training and monitoring.

What am I being asked to do and how long will it last?

You are being asked to do the following: allow the information obtained during your athletic monitoring/testing to be stored in this database that will be used for research purposes.

If you agree to take part in this Sports Science Research Repository, the information from your previous monitoring results will be added to the repository. In addition, the information that will be obtained during future monitoring while you are an athlete at ETSU will be added to the Sports Science Research Repository. The types of data that may be added to the repository include:

a. Dates and times of monitoring tests
b. Results of your body size tests, such as height, weight, skinfold measurements, muscle size (ultrasound or DEXA) and other similar tests
c. Results of your hydration tests
d. Results of your vertical jump tests
e. Results of your isometric pull tests
f. Results of your blood work
g. Results of monitoring tests that are a specific part of your sport (for example, results of agility tests or sprints)

APPROVED By the ETSU IRB SEP 14 2015 By [signature] Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES SEP 13 2016 ETSU IRB

In the future, a researcher may wish to conduct research in the field of sports science that requires information such as yours. That researcher would then ask the Sports Science Research Repository for information that includes your data, for a specific research study. The data will be used primarily by researchers at ETSU. However, there may also be collaborative efforts with other universities and private companies that use the data. Your information will be maintained by ETSU for such research purposes as long as allowed by the law or until Dr. Stone or ETSU decides to discontinue the Sports Science Research Repository.

What possible harms or discomforts might I experience if I take part in this research?

Because this study involves the use of your personal information, there is a possible risk of loss of confidentiality. Although, very unlikely, this means that someone may be able to piece together data such that your identity could be discovered. To lower that risk, the researchers will protect the data base by limiting access to the computer(s) in which access to the data is possible. Your data will not be provided to anyone without a sound research question (s) and without IRB approval or determination of non-human subject research.

What are the possible benefits I may experience form taking part in this research?

There is no direct benefit to the participant by permitting the investigators to add their performance information into the research repository. However,, the repository may contribute to the general knowledge of enhancing athletic performance, reducing the risks associated with over-training and aid in the prevention of injuries related to training or participation in sport programs.

Do I have to participate in this study?

Your participation in this research data base is entirely voluntary. You should feel free to ask questions as they occur to you. Your questions should be answered clearly and to your satisfaction. You are free to withdraw at any time without fear of reprisal from the investigators and you will not lose any benefits to which you would otherwise be entitled. If you are an ETSU student, your course grades also will not be impacted by your decision to participate or withdraw from the research repository. If you decide to withdraw your consent, you can have your data removed from the repository. To withdraw from the repository, contact Dr. Mike Stone (423-439-5796) or Mark South (423-439-4655).

How will you keep the information you collect about me secure? How long will you keep it? Who will know that I took part in this research and learn personal information about me?

For athletes already associated with the ETSU Olympic training site, the information that will be entered in this Sports Science Research Repository is already used for non-research purposes as part of your athlete monitoring. For non ETSU associated athletes your data for testing will be added to the repository shortly after the data collection. This document only applies to the information that becomes part of the repository for future research purposes.

The Sports Science Research Repository paper records will be kept in locked filing cabinets, and we will store electronic records on password protected computers. A copy of the records from this study will be stored in the Exercise and sports Science Laboratory (Mini-Dome E-113) for at least 5 years after the end of this research. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the ETSU IRB, and personnel particular to this research in the Sports Science department have access to the study records.

The Sports Science Research Repository will follow all legal requirements before releasing your information to others for research in the future. For example, future use of identifiable repository data for research would require review by the East Tennessee State University Institutional Review Board (IRB). The researcher would be required to submit the IRB's decision to the Sports Science Research Repository in order to obtain release of your information for research.

Who can I contact if I have questions?

If you have any questions, problems or research-related problems at any time, you may call (Mike Stone) at (423-439-5796), or (Dr. Mike Ramsey) at (423-439-4655). You may call the Chair of the Institutional Review Board at 423-439-6054 for any questions you may have about your rights as a research subject. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB Coordinator at 423/439-6055 or 423/439/6002.

APPROVED By the ETSU IRB SEP 14 2015 By Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES SEP 13 2016 ETSU IRB

PRINCIPAL INVESTIGATOR: Michael H. Stone___________________________

TITLE OF PROJECT: Sport Science Research Repository (Non ETSU Athletes)___

By signing below, you confirm that you have read or had this document read to you, that you have been given the chance to ask questions and to discuss your participation with the person obtaining your consent, that you have decided to participate, and that a copy of this form has been given to you.

By signing this informed consent I verify that I am at least 18 years old.

____

SIGNATURE OF PARTICIPANT DATE

____

PRINTED NAME OF PARTICIPANT DATE

____

SIGNATURE OF INVESTIGATOR DATE

APPROVED
By the ETSU IRB
SEP 14 2015
By ______
Chair/IRB Coordinator

DOCUMENT VERSION EXPIRES
SEP 13 2016
ETSU IRB

APPENDIX C: Sample Data from Isometric Mid-Thigh Pull

Athlete	Testing date	Analyzed by	mPF (N)	mT to PF (ms	mF50 (N)	mF90 (N)
	9.14.15	EDM	3104.703	4179	1663.724	2177.599

mF200 (N)	mF250 (N)	mRFD50 (N/s	mRFD90 (N/s	mRFD200 (N/	mRFD250 (N/	mRFDPF (N/s
2525.667	2590.236	9679.174	11087.036	6729.506	5641.881	446.659

mImpulse50	mImpulse90	mImpulse20(	mImpulse25(	mImpulsePF	Trial #	FP offset
67.99	146.541	407.138	535.481	11526.926	1	-9.784

A-1	A-2	Mean force (	PF (N)	Min. Force (N	T to PF (ms)	F50 (N)
16361	23240	2577.787	3215.492	573.046	4228	1617.643

F90 (N)	F200 (N)	F250 (N)	RFD50 (N/s)	RFD90 (N/s)	RFD200 (N/s)	RFD250 (N/s)
2092.701	2537.743	2627.157	12538.19	12244.077	7735.047	6545.692

RFDPF (N/s)	Impulse50 (N	Impulse90 (N	Impulse200 (	Impulse250 (	ImpulsePF (N	Trial #
516.753	61.621	138.528	385.537	515.371	12404.116	2

FP offset	B-1	B-2	Mean force (	PF (N)	Min. force (N	T to PF (ms)
-9.784	61494	68513	2365.821	2993.913	663.225	4130

F50 (N)	F90 (N)	F200 (N)	F250 (N)	RFD50 (N/s)	RFD90 (N/s)	RFD200 (N/s)
1709.805	2262.497	2513.59	2553.315	6820.158	9929.995	5723.965

RFD250 (N/s)	RFDPF (N/s)	Impulse50 (N	Impulse90 (N	Impulse200 (	Impulse250 (	ImpulsePF (N
4738.071	376.564	74.358	154.553	428.739	555.591	10649.736

FP1 slope	FP1 intercept	FP2 slope	FP2 intercept	Note
8385.654	3.284	7450.952	-8.832	

APPENDIX D: Sample Data from Optojump

Test	Date	Time	#	L/R	TFlight	TContact	Height	Pace[step/s]	Pace[step/m]	Step
Gait Test - Re	9/28/2015	11:12:07 AM	External trigge	L						142
Gait Test - Re	9/28/2015	11:12:07 AM	1	L	0.052	0.184	0.3	4.24	254.24	116
Gait Test - Re	9/28/2015	11:12:07 AM	2	R	0.085	0.164	0.9	4.02	240.96	125
Gait Test - Re	9/28/2015	11:12:07 AM	3	L	0.095	0.133	1.1	4.39	263.16	142
Gait Test - Re	9/28/2015	11:12:07 AM	4	R	0.089	0.124	1	4.69	281.69	146
Gait Test - Re	9/28/2015	11:12:07 AM	5	L	0.099	0.127	1.2	4.42	265.49	167
Gait Test - Re	9/28/2015	11:12:07 AM	6	R	0.106	0.119	1.4	4.44	266.67	171
Gait Test - Re	9/28/2015	11:12:07 AM	Split 1							
Gait Test - Re	9/28/2015	11:12:07 AM	7	L	0.114	0.109	1.6	4.48	269.06	179
Gait Test - Re	9/28/2015	11:12:07 AM	8	R	0.112	0.101	1.5	4.69	281.69	185
Gait Test - Re	9/28/2015	11:12:07 AM	9	L	0.114	0.109	1.6	4.48	269.06	190
Gait Test - Re	9/28/2015	11:12:07 AM	10	R	0.119	0.097	1.7	4.63	277.78	197
Gait Test - Re	9/28/2015	11:12:07 AM	11	L	0.115	0.105	1.6	4.55	272.73	207
Gait Test - Re	9/28/2015	11:12:07 AM	External trigge							
Gait Test - Re	9/28/2015	11:08:33 AM	External trigge	L						143
Gait Test - Re	9/28/2015	11:08:33 AM	1	L	0.042	0.195	0.2	4.22	253.16	117
Gait Test - Re	9/28/2015	11:08:33 AM	2	R	0.076	0.175	0.7	3.98	239.04	128
Gait Test - Re	9/28/2015	11:08:33 AM	3	L	0.088	0.14	0.9	4.39	263.16	139
Gait Test - Re	9/28/2015	11:08:33 AM	4	R	0.086	0.124	0.9	4.76	285.71	152
Gait Test - Re	9/28/2015	11:08:33 AM	5	L	0.096	0.134	1.1	4.35	260.87	168
Gait Test - Re	9/28/2015	11:08:33 AM	6	R	0.107	0.119	1.4	4.42	265.49	174
Gait Test - Re	9/28/2015	11:08:33 AM	Split 1							
Gait Test - Re	9/28/2015	11:08:33 AM	7	L	0.115	0.112	1.6	4.41	264.32	183
Gait Test - Re	9/28/2015	11:08:33 AM	8	R	0.101	0.103	1.3	4.9	294.12	180
Gait Test - Re	9/28/2015	11:08:33 AM	9	L	0.121	0.111	1.8	4.31	258.62	197
Gait Test - Re	9/28/2015	11:08:33 AM	10	R	0.109	0.096	1.5	4.88	292.68	190
Gait Test - Re	9/28/2015	11:08:33 AM	11	L	0.121	0.106	1.8	4.41	264.32	208
Gait Test - Re	9/28/2015	11:08:33 AM	External trigge							
Gait Test - Re	9/28/2015	11:04:07 AM	External trigge	L						141
Gait Test - Re	9/28/2015	11:04:07 AM	1	R	0.063	0.18	0.5	4.12	246.91	111
Gait Test - Re	9/28/2015	11:04:07 AM	2	L	0.09	0.147	1	4.22	253.16	125
Gait Test - Re	9/28/2015	11:04:07 AM	3	R	0.094	0.132	1.1	4.42	265.49	138
Gait Test - Re	9/28/2015	11:04:07 AM	4	L	0.098	0.124	1.2	4.5	270.27	151
Gait Test - Re	9/28/2015	11:04:07 AM	5	R	0.103	0.125	1.3	4.39	263.16	159
Gait Test - Re	9/28/2015	11:04:07 AM	6	L	0.115	0.112	1.6	4.41	264.32	174
Gait Test - Re	9/28/2015	11:04:07 AM	Split 1							
Gait Test - Re	9/28/2015	11:04:07 AM	7	R	0.113	0.113	1.6	4.42	265.49	178
Gait Test - Re	9/28/2015	11:04:07 AM	8	L	0.117	0.1	1.7	4.61	276.5	181
Gait Test - Re	9/28/2015	11:04:07 AM	9	R	0.111	0.109	1.5	4.55	272.73	184
Gait Test - Re	9/28/2015	11:04:07 AM	10	L	0.118	0.1	1.7	4.59	275.23	197
Gait Test - Re	9/28/2015	11:04:07 AM	11	R	0.12	0.105	1.8	4.44	266.67	200

VITA

ERIC DANIEL MAGRUM

Education:	M.S. Sport Science and Coach Education, East Tennessee State University, Johnson City, TN, 2017
	B.S. Kinesiology, Bowling Green State University, Bowling Green, OH, 2014
	Eastwood High School, Pemberville, OH, 2010
Professional Experience:	Strength and Conditioning Coach/Sport Scientist, East Tennessee State University Women's Volleyball, 2015-2017
	Strength and Conditioning Coach/Sport Scientist, Eastwood High School, 2011-2015
	Assistant Track and Field Coach, Eastwood High School, 2011-2015
Publications:	Carroll, K., Goodin, J., Magrum, E., Bernards, J., Blaisdale, B., & Dotterweich, A. (2016). Cardiovascular adaptations to resistance training. *Journal of Strength and Conditioning Research. In Review*
	Miller, J. L., Magrum, E. D., Stone, M. Practical monitoring techniques: Using ongoing monitoring tactics for the long term development of athletic performance. In proceedings of: 11th Annual Coaches & Sport Science College: (Goodin, J., Carroll, K., Bingham, G., editors). Johnson City, TN. December 9-10, 2016.
	Magrum, E. D., Bellon, C. R., DeWeese, B. H. A theoretical model for the enhancement of amputee sprint performance. In proceedings of: 10th Annual Coaches & Sport Science College: (A. Swisher & J. Goodin, editors). Johnson City, TN. December 11-12, 2015.