Explosive Training and the Effect

on Measures of Power in Novice Marathoners

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Dedication

This thesis is dedicated to my family for always pushing me to accomplish my goals.

Abstract

Coaches are constantly working to enhance the abilities of their athletes through various training modalities within the current body of training methodologies. However, speculation about proper exercises and volume necessary to achieve positive outcomes are still widely varied. Specifically within the realm of team sports where both endurance and speed components are necessary, like in soccer, lacrosse and basketball, it is essential to spend adequate time under task in both aerobic and anaerobic energy systems in order to achieve positive performance outcomes. Explosive training, involving sprinting and plyometric exercises, have been long been used to improve athletic performance within sports involving power components like jumping, sprinting, and acceleration through changes in direction. This is study aims to understand if one session per week of explosive training will have a positive effect on measures of power determined by the Wingate test after twelve weeks when applied in conjunction with high-volume aerobic training. Twenty-two novice marathon runners participated in the current study and were randomly placed into either the CORE or the PLYO group. Participants were pre- and post-tested in the Wingate test for outcomes in anaerobic capacity (AnC), anaerobic power (AnP) and fatigue index (FI). Results indicated that there was no effect of training type pre- to post-test on AnC (P: 7.79 ± 1.04; 7.98 ± 1.13. C: 7.83 ± 1.34: 7.97 ± 1.25), AnP (P: 9.05 ± 0.95; 9.23 ± 1.10. C: 9.44 ± 1.55; 9.74 ± 1.30), or FI (P: 8.02 ± 2.42; 7.72 ± 1.91. C: 10.06 ± 3.40; 10.59 ± 3.59). Therefore, it may be concluded from the current study that one training session per week of PLYO training is not adequate to make necessary improvements in power. Multiple weekly exposure may be essential to increasing gains in anaerobic power and capacity for sports with both endurance and power components.

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Introduction

Explosive training have been associated with improved athletic performance through power movements such as jumping, bounding, and sprinting. Plyometric training can affect the ability for muscles to better recruit elastic energy and muscle power development (Saunders et al., 2006). When jumping, concentric force generated in the quadriceps, hamstrings and gluteus maximus is needed to initiate motion and propel the body. Upon landing, muscles work eccentrically to decelerate movement, while stabilizing knee and hip joints on ground contact (Wilkerson et al., 2004). The Wingate test is commonly used to measure power and anaerobic parameters. The question that this study attempts to answer is whether the adaptations to explosive plyometric and sprint training will transfer to changes in performance on the Wingate test in a population simultaneously undergoing high-volume aerobic training.

Drop jump training has been found to significantly increase maximal force development during the eccentric phase due to the compounded force of gravity upon the body (Lockie, Murphy, Schultz, Knight, & Janse De Jonge, 2012; Villarreal, Gonzalez-Badillo, & Izquierdo, 2008). A shorter, quicker stretch shortening cycle (SSC), relies more heavily on the reuse of elastic energy than a slow stretch-shortening cycle, like those used in weight training (Wilson & Flanagan, 2008). Repetitive jumping can then influence adaptation on the physical structures of the lower limbs so as to better handle rapid, repetitive, weighted impact.

Plyometric exercises must be specific in nature to reach the desired outcome (Markovic & Mikulic, 2010) and must be planned with adequate progression, volume and intensity (Lockie et al., 2012). Studies have shown that multiple sessions for six weeks or more of explosive training can enhance various performance tests in both power and speed (Chimera, Swanik, Swanik, & Straub, 2004; Dodd & Alvar, 2007; Lockie et al., 2012; Markovic, Jukic, Milanovic, & Metikos, 2007; Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999; Sankey, Jones, & Bampouras, 2008; Saunders et al., 2006; Spurrs, Murphy, & Watsford, 2003; Turner, Owings, & Schwane, 2003), whereas only one study has shown that one session per week is adequate to influence adaptation (Villarreal et al., 2008).

Short and long distance sprinters in track (100, 200 and 400 meters) require both explosive power and sustained speed to be successful in their specific track events. Both modalities need to be trained in a matter to make adaptation at both the muscle and bone level, but with caution to prevent injury and over-training (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999; Villarreal et al., 2008). Plyometric training is just one activity of many that is practiced specific to sports that involve an explosive component. Traditionally, repeat sprint sets with adequate rest intervals have been used to train sprinters, sometimes in conjunction with strength and power training (Kin-Isler, Ariburun, Ozkan, Aytar, & Tandogan, 2008). However, repeated sprint sets can take up a sufficient amount of time during practice and perhaps does not effectively utilize practice time training desired the energy systems and muscle fibers (Minahan, Chia, & Inbar, 2007).

Endurance athletes, specifically those running cross country and track events of 1500-10,000 meters, typically utilize training modules which focus on endurance running at an aerobic threshold or interval training calculated off of performance times. However, research has indicated the possible benefits of including lower-body explosive training through plyometric and sprint modalitites to enhance endurance running performance (Paavolainen et al., 1999;

Saunders et al., 2006; Spurrs et al., 2003; Turner et al., 2003). Core training has also been widely used within a variety of training programs, especially within endurance training programs, due to its ability to incorporate strengthening while decreasing systemic bone stress. Decreased impact allows for better injury prevention largely due to enhanced postural stability during running and other complex coordinated body movements (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). Core training has been shown to build strength due to increasing the stiffness of the torso and thereby allowing more power generation, or power maintenance, by the hip musculature (Bliss & Teeple, 2005; McGill, 2010).

The neuromuscular mechanism that enhances a distance runner's efficiency through plyometric training causes more efficient ground reaction force (GRF) with each step. As a result, runners spend less energy in downward inertia, less contact with the ground, so that more energy can be conserved for use further into continued performance (Kyröläinen, Belli, & Komi, 2001; Lockie et al., 2012; Wilson & Flanagan, 2008). If a runner has efficient running economy at slower, submaximal speeds, it has been suggested that they will also have better running economy at faster speeds (Williams & Cavanaugh, 1987).

In theory, jump training could also impact the ability of sprinters to be able to decrease their ground contact time and increase their GRF, thus making them more efficient. However, sprinting requires energy contribution from the ATP and ATP-PCr systems, as well as, a different muscle fiber recruitment pattern compared to distance running. The ATP, ATP-PCr and Lactate system are all utilized during 100m, 200m, and 400m maximum sprinting efforts (Gastin, 2001). While jumping and in the initial phase of sprinting, the ATP energy system is being utilized for explosive power. As the sprint increases in duration, activation of the ATP-PCr energy system takes place to utilize phosphagens and phosphocreatine (PCr). After sprinting maximally for approximately 100m, with individual variability, an accumulation of lactic acid, decreased pH and reduced stores of PCr all create an internal environment that can cause work output to be decreased (Gastin, 2001).

Depending on a person's training and anaerobic capacity, measures of peak power (PP), mean power (MP) and fatigue index (FI), will be expressed differently (Zagatto et al., 2009). It has been postulated that an individual's anaerobic capacity, or the ability to perform high intensity exercise, like sprinting, over a long duration, is best measured by the fatigue index (Minahan et al., 2007) and can contribute to enhanced repeated sprint ability. Many team sports require intermittent sprints, such as soccer, lacrosse, football and basketball to name a few. Repeated intermittent sprinting requires the ability to produce short bursts of power while still having the aerobic fitness to recover so as to maintain the capacity of continued ability to sprint at full capacity (Meckel, Machnai, & Eliakim, 2009).

The Wingate test has long been used to determine anaerobic power through measurements of PP, MP and FI (Bar-Or, 1987). Though many studies have investigated the reliability and validity of measures from the Wingate test to sprinting, jumping and team sports, not many have looked at the relationship of how these measures relates to athletic performance. Researchers have argued that the Wingate does not utilize the same amount of energy that sprinting does due to the amount of mechanical work the body is doing, therefore the specificity of a test must be taken into consideration as a limitation of this measure (Aziz & Chuan, 2004; Queiroga et al., 2013; Zagatto et al., 2009). Some studies have attempted to validate other methods of anaerobic power, like the repeated anaerobic sprint test, or RAST, however not all are in agreement of test re-test reliability between measures (Aziz & Chuan, 2004; Queiroga et al., 2013; Reza & Rastegar, 2012; Zagatto et al., 2009).

In track, where the individual performance in non-relay events determines the outcome of an event, the importance of identifying contributors specific to outcome measures should be considered. The initial phase, or start, is explosive, reaching maximal velocity in the shortest amount of time. The second phase, or acceleration phase, covers maximal distance with maximal velocity. And the third phase, the maintenance phase, has to be energy efficient while continuing in velocity while minimizing levels of acidity at the muscle level. Therefore, a sprinter has to combine a tri-phasic anaerobic energy output that is efficient from start to finish. All three phases of sprinting may be enhanced through a more highly trained anaerobic system (Gastin, 2001).

A 30-second Wingate test and a 200m race are similar in time to completion and anaerobic energy system utilization. Though no studies have looked at this specific relationship, this study will look to compare a similar time frame of anaerobic power output through the Wingate test to contribute to the current body of research. Though numerous studies have found test outcome improvements with explosive training, no studies have looked at the implementation of a similar training intervention to specifically enhance Wingate test power outcomes.

The purpose of this study is to identify the effects of explosive training, including plyometric and sprint training modalities, when compared to core training on decreasing the fatigue index and increasing anaerobic capacity and power, as measured by the Wingate Test in an aerobically trained population. It is hypothesized that, given previous research on plyometric training and neuromuscular adaptations that occur, an explosive training intervention will be successful in improving these power performance measures.

Core stability training has been shown to improve strength without increasing unnecessary bone stress in endurance runners and will be used as a training method in our comparison group in order to match time spent training between groups. Determining if explosive training enhances power measures in an endurance population could contribute to the way athletes are trained within the realm of both track events as well as team sports that have both aerobic and anaerobic components, such as soccer, hockey, and lacrosse.

Literature Review

Distance Running and Running Economy

Kyröläinen et al. (2001) suggested that 80% of running economy (RE) could be explained by the braking phase of average horizontal running forces. Chang and Kram (1999) found that 33% of the total metabolic cost of running is based on horizontal running forces. During the braking part of the stride, increased horizontal momentum leads to higher activation of the major running muscles to accommodate force of impact. This directly applies to the stability of the mechanical structure upon foot contact while running. In more economical runners, angular displacement in the knee and ankle joints are decreased during the breaking phase. Increased EMG activity in the biceps femoris occurs as well as increased angular velocity at the hip joint. This unveils the role of hip extensor muscles and how they enhance the exertion of power in each stride and thus the braking forces needed to decelerate at each heel strike (Kyröläinen et al., 2001).

Training Interventions and the Effects on Measures of Power

Most elite long distance runners have three major factors that contribute to their ability to run long distances at higher velocities. First, elite runners typically have high VO_{2max} values, indicating high aerobic capacity and oxygen uptake (Conley & Krahenbuhl, 1979; Rowell, 2011). Second, lactate threshold, or the ability to utilize fat as a fuel source. Having a low respiratory exchange ratio (RER) allows for maintaining high intensity with low energy expenditure. An extremely efficient runner can maintain RER values below 1.0 indicating an efficiency of lactate utilization which translates to better performance (Billat et al., 1999). Thirdly, it has been shown that running economy may be a more important determinant of distance running success than VO_{2max} or RER (Morgan, Baldini, Martin, & Kohrt, 1989; Spurrs et al., 2003).

Running economy (RE) is defined as the oxygen requirement necessary for a runner during steady-state, submaximal running (Conley & Krahenbuhl, 1979; Morgan et al., 1989). Runners who have higher RE use less energy during distance running than runners with low RE (Thomas, Fernhall, & Granat, 1999). Conley & Krahenbuhl (1979) found that running economy was a better predictor of distance performance than VO_{2max}. Several follow-up studies have been performed to confirm this result (Conley & Krahenbuhl, 1979; Morgan et al., 1989; Paavolainen et al., 1999; Saunders, Pyne, Telford, & Hawley, 2004).

Although many things contribute to factors associated with RE, genetic factors include gender, muscle-fiber distribution, and to some extent, aerobic capacity. Other factors include body composition, level of training, heart rate, fatigue, VO_{2max}, and environmental characteristics like the temperature and humidity (Morgan et al., 1989; Bailey and Pate, 1991; Rowell, 2011; Saunders et al., 2006). Some factors of RE can be modified through means of training.

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Running Economy and Musculotendinous Stiffness (MTS)

Paavolainen et al. (1999) found that a plyometric training regimen had significant improvements in 20m speed, the 5 jump test and in contact times during the 5k run. Plyometric training has been shown to increase running economy by means of musculotendinous stiffness (Spurrs et al., 2003). Researchers suggested that the increase in musculotendon stiffness enhances the ability of the stretch shortening cycle in the lower limbs (Kyröläinen et al., 2001; Walshe, Wilson, & Murphy, 1996; Wilson & Flanagan, 2008). As a result of jump training, MTS increases so as to greater handle the demands of plyometrics and the instability they inflict on an individual's joints (Markovic & Mikulic, 2010).

However, some studies have found that a more compliant musculotendinous unit (MTU) offers a better stretch shortening cycle (SSC) due to its ability to better store and return elastic energy (Markovic & Mikulic, 2010; Wilson & Flanagan, 2008). In Kubo et al. (2007), a 12 week plyometric intervention was used to assess achilles tendon stiffness during drop jumps (DJ). Post-test measures revealed a 63% increase in ankle stiffness but no significant results in achilles tendon stiffness. Researchers concluded that maximal tendon length allowed for better stored energy and translation to force during jumping performance (Kubo et al., 2007).

Overall, changes to the neuromuscular system, including the musculotendinous unit, can impact measures of performance and running economy. Differing measurement techniques and analysis methods may be the reason for these varied results. However, more support has been shown on the side of a stiffer MTU having better ability to exert force more efficiently (Walshe et al., 1996; Spurrs et al., 2003; Wilson & Flanagan, 2008) and therefore, less energy is wasted in downward momentum. It has been suggested that plyometric training can reduce ground contact time while running due to higher MTS (Sankey et al., 2008).

Plyometric Training Volume

Developing a training schedule that provides the optimal amount of time under task is essential to creating adaptation without inducing an over-training effect (Billat et al., 1999; Villarreal et al., 2008). Some studies have shown that a six to nine week intervention (Paavolainen et al., 1999; Spurrs et al., 2003; Saunders et al., 2006) with two to three plyometric training sessions per week can have significant improvements in RE. Only one study has shown that one session per week for seven weeks has performance improvements in 20m sprint time, jumping contact times, and maximal strength (Villarreal et al., 2008).

Spurrs, et al. (2003) investigated 17 well-trained male runners who participated in a six week study of either a jump training intervention in concurrence with their regular running schedule (experimental group) or continued their normal running training (control group). The experimental group had two jump-training sessions for the first three weeks, then three sessions the last three weeks. During post-testing, athletes who had taken part in the plyometric intervention saw significant improvements in measures of running economy ($p<0.05$) and 3-km time performance ($p<0.05$), as well as in counter movement jump (CMJ) height, a five-bound test ($p<0.01$), and musculotendinous stiffness ($p<0.05$) (Spurrs et al., 2003).

Further, Saunders et al. (2006) implemented a plyometric intervention for nine weeks at three times a week with 15 highly trained runners, and found that RE was significantly improved in a faster running speed of 18 km/h (11.2 mph) ($p<0.05$), but not in slower speeds of 14 (8.7 mph) or 16 km/h (9.95 mph). Researchers also looked at force plate values during a loaded squat jump and a 5-jump plyometric test to analyze ground reaction force (GRF) values. VO_{2max} test values, respiratory exchange ratio (RER), heart rate (HR), stride rate (SR), and blood lactate values were all taken as well during pre- and post-testing, however no significant changes occurred within any of these variables ($p<0.05$) (Saunders et al., 2006).

Turner et al. (2003), looked at 18 trained male and female distance runners who had been training for at least six months prior to the start of the study. Both the control and experimental groups continued their training throughout the six weeks of the present study, however, the experimental group also completed three sessions per week of plyometric training. Subjects were pre and post-tested for RE at three different submaximal running velocities, VO_{2max} values, and various jumping tests. These jumping tests included the CMJ, a static jump in which subjects had no countermovement, a ratio between these two jumps, as well as ratios for jumping efficiency between CMJ and the static jump. At the end of the six weeks of training, the experimental group averaged higher values than the control group in RE, but there were no significant changes in any other test values between groups.

Paavolainen et al. (1999), conducted a nine week plyometric intervention with 22 elite male cross country runners. Experimental and control groups remained consistent in their time spent in training, however, the experimental group increased their plyometric training and decreased their running volume during the intervention. In increments of three weeks, the experimental group increased the amount of volume was spent on plyometric training and decreased time running. After nine weeks of this progression in plyometric training, the experimental group had significant improvement ($p<0.05$) in 5km time, RE, and in maximal anaerobic velocity, as well as in a 5-bound test and 20m sprint ($p<0.01$) (Paavolainen et al., 1999).

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Plyometrics and Ground Contact Time

GRF increases as speed increases (Kyröläinen et al., 2001), so the ability to handle higher GRF forces becomes a necessity for sprinters as opposed to most distance runners. While sprinting or jumping, the SSC occurs very rapidly. Sankey et al. (2008) implemented a plyometric intervention for six weeks and analyzed drop-jump contact time, flight time, and reactive strength index (RSI), finding significant decreases in contact time between the intervention and control group.

In contrast, Lockie et al. (2012) looked at the impacts of four different training interventions on field sport athletes in measures of strength, power and ground contact time during sprinting. Free Sprint Training (FST), Resisted Sprint Training (RST), Weight Training (WT) and Plyometric Training (PT) protocols were used to determine within group differences that were specific to each training method. Part of their plyometric training included bounding exercises, during which, alternating strides are used while trying to gain the most distance with each stride. GRF during bounding increases flight time and vertical force while working to extend distance as well. It was concluded that performing bounds can eventually lead to a more effective gait while running due to increasing horizontal forces in each stride (Lockie et al., 2012; Støren, Helgerud, & Hoff, 2011).

However, none of the training protocols decreased ground contact time during 10m sprint testing. In fact, foot contact time was increased while step frequency decreased, meaning that subjects were taking longer initial sprinting strides. In the FST group, changes in horizontal power were positively correlated to stride length which contributed to increased mean ground contact time between the first 5m, and between 5m and 10m of a sprint. Even though ground contact time increased, flight time actually decreased, lending to a more explosive start up to the first five meters (Lockie et al., 2012). Reactive strength index (RSI) was also significantly improved which was due to the subjects having a more efficient ground contact from foot strike to push off (Lockie et al., 2012).

Kyröläinen et al. (2001), found that upon foot strike, there was higher activation of antagonist muscles within the leg; specifically vastus lateralis to biceps femoris and gastrocnemius to tibialis anterior. Researchers concluded that increased co-activation of these muscles indicated increased stiffness in the ankle and knee joints. This stiffness is directly correlated to better force output during the push off phase of the stride, again lending to the argument of how higher musculotendinous stiffness in the lower limbs creates a better SSC with each stride (Kyröläinen et al., 2001; Wilson & Flanagan, 2008).

The ability of the limb to handle quicker eccentric muscular loading to concentric contraction allows for more effective deceleration to immediate acceleration (Kale, Asçi, Bayrak, & Açikada, 2009; Kyröläinen et al., 2001; Lockie et al., 2012; Wilkerson et al., 2004; Wilson & Flanagan, 2008). This leads to better RSI, or reactive power, which is the main contributing factor during the initial acceleration phase of a sprint (Lockie et al., 2012; Markovic et al., 2007). These results indicate that plyometric and/or sprint training can contribute to explosive power in the initial phase of sprinting.

Along with higher activation of leg muscles during sprinting and jumping, muscle hypertrophy has been noted (Malisoux et al., 2006). Malisoux et al. (2006) put eight subjects through an eight week plyometric program with three sessions per week. Post-training resulted in significant improvements in the static jump, countermovement jump, shuttle-run test, and the leg-press. However, researchers also looked at physical changes within the muscle fibers of the vastus lateralis muscle. Muscle biopsies were extracted from each subject to determine changes in muscle fiber diameter and number. Results indicated that the number of Type IIa fibers significantly increased by eight percent. Also, muscle fiber diameter increased in Type I by 11%, Type IIa fibers saw a 10% increase and Type IIx fibers increased by 15% following the plyometric intervention (Malisoux et al., 2006). However, there is conflicting evidence within the literature that hypertrophy within Type I fibers has positive outcomes in performance.

Energy Systems

The energy systems used in anaerobic events depend greatly on a number of factors. Similar with running economy, certain genetic and environmental factors play into peak performance of a person to perform in anaerobic events (Morgan et al., 1989; Saunders et al., 2006). It is widely known that Type IIx fibers are primarily responsible for explosiveness and speed whereas Type I are primarily for endurance. Type IIa fibers have the capability to greatly determine anaerobic capacity due to their ability to be highly influenced by training (Putman, Xu, Gillies, MacLean, & Bell, 2004). However, it is the fiber distribution and interplay between these fibers that determine a person's ability to maintain speed over longer distances (Crowther, Jubrias, Gronka, & Conley, 2002).

Explosive training, using plyometrics, can result in hypertrophy within all three muscle types (Malisoux et al., 2006), specific to fiber type transition within Type IIa fibers (Putman et al., 2004). The potential for plyometric and sprint training to create better efficiency at the muscle level and contribute to better anaerobic performance potentially could also contribute to aerobic performance. However, though increases in fiber cross-sectional area and fiber type transitions can occur with both strength training and combining strength with endurance training (Putman et al., 2004), there are too many varied outcomes within the current body of research on the specificity of the adaptation and the relationship to performance.

Core Training

Core musculature functions collaboratively in complex and multidirectional ways. Thus, one exercise, like a crunch, only works through a single range of motion and does not adequately utilize all core muscles. Therefore, just like any strength program must include simplistic exercises that target specific muscle groups, it must also include exercises that involve the coactivation of numerous muscles, a core training program must be just as dynamic (Bliss & Teeple, 2005).

Adequate progression must also be taken into consideration; starting out with simpler, more isolated exercises and then progressing to more advanced exercises (McGill, 2010). Core training can enhance better stability within the lumbopelvic region, offering an athlete a more controlled platform to prevent extraneous movement during sport. A more stable core creates a stiffer hip structure so as to minimize trunk movement. This allows the limbs to exert more force during sport while also minimizing the chance for injury (Bliss & Teeple, 2005; Leetun et al., 2004).

Due to the overemphasis of endurance training within sports with primarily endurance components, highly aerobic sports teams have often used core stability exercises so as to utilize strengthening modalities that minimize any extra bone stress already incurred during high volume endurance training. Over the course of a single sports season, Leetun et al. (2004) looked at both male and female basketball and track athletes to determine if core strength and stability weakness was a potential determinant of injury. Researchers found that hip external rotation and hip abduction weakness was directly correlated with incidence of injury in the back and lower extremities. Hip external rotation weakness was the primary significant determinant of injury status ($p<0.05$) for athletes involved within their study.

Wingate versus RAST

The RAST (Repeated Anaerobic Sprint Test) has been used with more frequency in recent research to determine anaerobic power measures (Reza & Rastegar, 2012; Zagatto et al., 2009). Some researchers have found that the RAST protocol better mimics total body energy systems and is more sport specific compared to the validated Wingate test. Although the WAnT only utilizes lower body measures of power and fatigue index, the RAST has had mixed outcomes due to the variability of protocols used in testing (Aziz & Chuan, 2004; Queiroga et al., 2013; Reza & Rastegar, 2012; Zagatto et al., 2009).

Zagatto et al. (2009) determined that PP and MP were higher during the RAST protocol versus the Wingate test. This is in contrast to what Queiroga et al. (2013) found when comparing the two measures. In fact, Wingate measures were significantly higher for MP and PP ($p<0.05$), with the exception being in the performance decrement, or fatigue index (Queiroga et al., 2013). Aziz and Chuan (2004) and Zagatto et al. (2009) found significant correlations between FI between the Wingate test and RAST protocols ($p<0.05$), most studies have not found FI correlations between tests (Meckel et al., 2009; Queiroga et al., 2013; Reza & Rastegar, 2012).

Conclusion

There is little to no research currently that has looked at the effects of a combined plyometric and sprinting intervention on measures of power (Anaerobic or Peak Power, Anaerobic Capacity or Mean Power, and Fatigue Index) within the Wingate test. Given that plyometric and sprint training have shown improvements in other measures of power, like vertical jump and decreases in sprinting times with efficiency in ground contact times, it can be hypothesized that performance decrement, or fatigue index, may be improved as well as anaerobic capacity and power.

During endurance running, running economy is enhanced through changes in musculotendinous stiffness, which lead to greater efficiency on ground contact, decreased flight time and less wasted energy (Kyröläinen et al., 2001; Markovic & Mikulic, 2010; Paavolainen et al., 1999; Spurrs et al., 2003; Walshe, Wilson, & Murphy, 1996; Wilson & Flanagan, 2008). Thus, through plyometric training, repeated accelerated eccentric loading to concentric movement leads to adaptations at the neuromuscular level. When used in conjunction with other training methods like sprint training, plyometrics have the capacity of contributing to both anaerobic and aerobic energy system performance improvements.

While sprinting, positive changes in horizontal running forces help to propel a sprinter through space with a more explosive start drive (Kyröläinen et al., 2001; Lockie et al., 2012; Støren et al., 2011). Acceleration phase is enhanced through the ability of the limb to handle quicker SSC with more efficient eccentric to concentric contraction. Also, hypertrophic changes in muscle fibers allow for greater muscular endurance through the maintenance phase of sprinting, and could have an impact in the facilitation of recovery for intermittent sprint sports (Malisoux, et al., 2006; Putman, Xu, Gillies, MacLean, & Bell, 2004).

Though additional methods are being used to asses sprinting capacity for repeated bouts, like the RAST (Aziz & Chuan, 2004; Queiroga et al., 2013; Reza & Rastegar, 2012; Zagatto et al., 2009), the Wingate remains the standard for determining anaerobic power, capacity and fatigue index (Bar-Or, 1987). During repeated sprints, there is an interrelated combination of anaerobic and aerobic components that determine capability for muscles to sprint multiple bouts, but also recover and allow for adequate replacement of energy stores for the next sprint (Gastin, 2001; Meckel et al., 2009; Zagatto et al., 2009). As stated above, Fatigue Index is highly correlated with repeat sprint ability (Meckel et al., 2009; Minahan et al., 2007).

Practical implications for including a plyometric and sprint training regimen with athletes requires specific planning, progression and efficiency (Lockie et al., 2012; Markovic & Mikulic, 2010). It has been shown that low to moderate amounts of sessions (one to two), or total jumps per week (840), have the same performance outcomes as high amounts of volume, but with better training efficiency (Villarreal et al., 2008).

The goal of the research is to determine whether plyometric and sprint training, applied once a week for twelve weeks, has an effect on measures of anaerobic capacity, anaerobic power, or fatigue index in novice marathoners.

Methods

An experimental design approach was taken via a randomized control trial for the purpose of this study. After completion of testing, detailed below, participants were randomly placed into one of two intervention groups; either an explosive training group (PLYO) or a core stability group (CORE). Subjects were first stratified by sex then randomized further by performance to ensure each group had an equal proportion of high to low performance. This was accomplished by listing the Wingate scores from best to worst, then placing every other subject down the list into either PLYO or CORE groups to ensure one group was not weighted with higher performing participants than the other.

Participants

Participants were 23 novice marathon runners, 10 males (age = 21.5 ± 1.27 years; height = 70.4 ± 2.29 in; weight = 168.8 ± 17.04 lbs) and 13 females (age = 21.08 ± 1.32 years; height = 65.3 ± 2.24 in; weight = 141.0 ± 14.94 lbs). Recruitment for participation was through volunteer, self-selection from a convenience sample of students participating in a marathon training class (PE 1262 Marathon Training, University of Minnesota). Students were informed of the nature of the study, intentions for research, testing procedures, any risks involved with participation, and then asked to sign an informed consent for participation in the study (see Appendix A).

All participants ran as a group twice per week as part of the class while following a training plan that included two to three other days of self-motivated running workouts (See Appendix B). Training plans included either four or five days per week of scheduled running, depending on the level of experience of the runner. Runners self-selected what training plan was best for them.

Procedure

Wingate Test

Upon entering the Human and Sports Performance Lab, testing procedures and possible risks are reviewed with each subject and any questions are answered. Subjects were then asked remove their shoes for height and weight measurements. Height was measured in inches using the Accustat Genentech Stadiometer (San Francisco, CA). Weight was measured in pounds using ProDoc Detecto (PD300) scale (Webb City, MO) and then converted to kilograms for testing.

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This study was performed in conjunction within a larger study, thus the Wingate was performed in concurrence with a battery of other tests (See Appendix D). Prior to the Wingate test, a 33-minute, submaximal running test was performed as well as a Vertical Jump test using a force plate. However, adequate rest was ensured for all subjects so that necessary recovery could take place. Each subject was given at least five minutes rest after the running test and heart rate was monitored so as to ensure proper recovery.

Heart rate was monitored during the Wingate test using a Polar s810 wrist computer (Polar, Kempele, Finland). The 30-s Wingate Anaerobic power test (WAnT) was tested using the Veltron Dynafit Pro Cycle Ergometer with Racermate software (Racermate, Inc., Seattle, WA). Resistance load was set at 0.075kg per kg of the subject's body weight and was applied electronically to the flywheel. Seat height and handlebar height and length was adjusted for each subject so as to ensure proper form while cycling.

To warm up, the subject pedaled at 65-75 rpm on a Monark Cycle Ergometer (Monark Exercise AB 828E Ergomedic Testing Bike, Sweden) with no resistance for three minutes with a maximal effort sprint for five seconds at the end of every minute. After the warm-up, the subject was asked to dismount the bike and rest passively for three minutes.

After the rest period, the test participant mounted the Veltron Dynafit Pro Cycle Ergometer which was also adjusted for height and torso length. The subject was instructed to use the pedal toe clips and to stay seated throughout the test. The first ten seconds, the subject pedaled at 65-75 rpm with 50 watts of resistance. Then a three second period sprint occurred to allow the subject to reach maximal velocity. After the sprint period, the resistance load based on the subject's body weight was applied to the flywheel and the subject was verbally encouraged to continue and all-out effort for the remainder of the test. Each subject received consistent wording of encouragement so as to continue effort versus saying how many seconds remained in the test.

The subject remained on the cycle ergometer for a post-test, active recovery for two to three minutes or until their heart rate returned to below 60% MHR (determined in previous VO_{2max} testing). Lower body power was assessed for peak power, mean power and fatigue index (expressed as a percentage of power drop off between the highest and lowest work rate).

Intervention

Participants were informed that training would take an additional 15-20 minutes on top of their weekly marathon training schedule. They were also informed that their placement into a training group would be random and therefore not an elected option.

Due to the nature of distance training within our study population, it was determined that the comparison group needed to match training time with our experimental group so as to eliminate any adaptation based solely on extra volume within the PLYO group. Subjects were able to withdraw participation at any time during the study. All training sessions were monitored by research staff to ensure proper form and safe execution of all exercises.

Explosive Training (PLYO)

For each PLYO group session, a series of approximately 5-6 jumping and sprinting exercises were performed and varied from week to week. Jumping exercises included sets of 1-3 with 5-20 repetitions. For the sprinting exercises, only 3-6 repetitions were performed. Exercise progression was extremely important so as to not overload participants in too rapid a manner (Lockie et al., 2012; Markovic & Mikulic, 2010), especially since their running program dictated four to five days of endurance training in conjunction with participation within the current training intervention. Jump exercises included non-weighted exercises such as squat jumps, lunge jumps, depth jumps, box jumps, standing long jumps, cone jumps, single-leg hops, and alternate-leg bounding. Sprint exercises included 50-m build-up accelerations, flying 30-m sprints, 60-m sprint, and in-and-outs with 2x10-m fly zone. At least a minute of recovery was observed between all sets and exercises to ensure proper effort and form without a breakdown in mechanics due to fatigue. More recovery time was allowed if requested.

Core Stability (CORE)

The CORE group completed the same number of exercises and sets as the PLYO group, however were done primarily with body weight on abdominal/back and hip musculature. Exercises varied week to week and included crunches, side crunches, V-sits, planks, side planks, sit-ups, supermans, back extensions, bird-dogs, fire hydrants, bridging and Swiss-ball adductor squeezes. Again, progressive overload was taken into account in the design of this training regimen to ensure proper progression and adaptation as well as adequate rest was also given to ensure maximum effort for each exercise.

Statistical Analysis

Initial consideration of the data set must regard the dependent variables as correlated since three different sub-tests are related to one another in an overall assessment (the Wingate test). It is not clear whether weight change is correlated with these tests, so the more conservative approach was taken, which presumes that weight change is correlated with changes in each participant's test scores.

Correlated dependent variables raise the family-wise error rate, making it likely to find that a result is significant when it actually is not. Further, the measures taken in the pre-post tests for each participant are correlated. To account for these two types of correlations, a *doubly multivariate* approach is needed for the statistical analysis. A repeated measures multivariate general linear model was therefore selected for the statistical analysis.

The model incorporates both pre-test and post-test scores for each participant for each of the four measures: change in anaerobic capacity, change in anaerobic power, change in the fatigue index and in weight change. Independent variables include age and gender of participant, and training type (CORE or PLYO).

Results

Quantitative Analysis

Between Group Differences

Descriptive statistics (mean and standard deviation) of the scores for each test are presented in the tables that follow. Outcomes are presented by total participants for each type of training. Though 26 participants initially volunteered for participation in the study, two subjects dropped the marathon training class and one participant failed to complete 50% or more of the training sessions and thus were excluded. Therefore, data from 23 subjects is included in the analysis.

Training Interventions and the Effects on Measures of Power

Table 1: *Anaerobic Capacity (W/kg) Pre/Post-test Scores for all Participants*

	PLYO		CORE	
	Pre-test	Post-test	Pre-test	Post-test
N	11	11	12	12
Mean	7.79	7.98	7.83	7.97
St. Dev.	1.04	1.13	1.34	1.25
p-value	p = 0.676			

Table 2: *Anaerobic Power (W/kg) Pre/Post-test Scores for all Participants*

	PLYO		CORE	
	Pre-test	Post-test	Pre-test	Post-test
N	11	11	12	12
Mean	9.05	9.23	9.44	9.74
St. Dev.	0.95	1.10	1.55	1.30
p-value	p = 0.777			

Table 3: *Fatigue Index (W/s) Pre/Post-test Scores for all Participants*

	PLYO		CORE	
	Pre-test	Post-test	Pre-test	Post-test
N	11	11	12	12
Mean	8.02	7.72	10.06	10.59
St. Dev.	2.42	1.91	3.40	3.59
p-value	p = 0.441			

Table 4: *Weight (lbs) Pre/Post-test Scores for all Participants*

	PLYO		CORE	
	Pre-test	Post-test	Pre-test	Post-test
N	11	11	12	12
Mean	146.35	145.54	161.06	160.71
St. Dev.	18.66	17.21	21.95	20.86
p-value	p = 0.816			

A repeated measures general linear multivariate model was conducted to test the effect of the training intervention (CORE vs PLYO) on the three sub-tests of the Wingate test. The results showed there was no statistically significant difference between types of training on the subtests of anaerobic capacity, anaerobic power, or fatigue index (F (3, 19) =.346, p = 0.793, η^2 =

0.052) when comparing the scores before and after training. Since Pillai's trace is the most common test of multivariate models, these results are reported. Results showed that anaerobic capacity was improved with training, but the type of training was not significant as results were similar with both. Training did not have an effect on anaerobic power, fatigue index, or weight changes between groups.

The size of the *F*- statistics and related power between subjects for $F(3,19) = 1.644$, $p = 0.213$ suggests that the test is underpowered. In other words, an increase in sample size may have produced different results and pointed to a greater effect of training. Age ($F(4,13) = 1.637$, $p = 0.224$, $\eta^2 = 0.335$) and gender ($F(4,13) = 1.482$, $p = 0.264$, $\eta^2 = 0.313$) hint that they may produce effects that might emerge with a larger sample size.

Within Group Differences

Pre- to Post-test CORE Training Group

Across the participants in the CORE training group, from pre-test to post-test in the Wingate test, scores of Anaerobic Capacity, Anaerobic Power and Fatigue Index all increased on average. Of these, the Fatigue Index showed the greatest change. Participants in the Core Training Group ($n = 11$) lost an average of 0.35 pounds, with weight changes ranging from a 6.9 pound loss to an 8.9 pound gain. See Table 5 below.

Table 5. *Pre- and Post-test Differences in Wingate Test Variables within CORE Training Group*

	N	Minimum	Maximum	Mean	SD
Pre-post Difference in An. Capacity	12	-0.50	0.64	0.1283	0.35542
Pre-post Difference in An. Power	12	-1.10	2.22	0.2783	0.96956
Pre-post Difference in Fatigue Index	12	-4.35	5.05	0.4483	2.91778
Pre-post Difference in Weight	12	-6.90	8.90	-0.3545	4.89068
Valid N (listwise)	12				

Training Interventions and the Effects on Measures of Power

Pre- to Post-test PLYO Training Group

Across the participants in the PLYO training group (*n* = 12), scores of Anaerobic Capacity and Anaerobic Power increased whereas Fatigue Index decreased. Participants in the PLYO Training Group (*n* = 11) lost an average of 0.82 pounds, with weight changes ranging from an 11.2 pound loss to a 3.7 pound gain. See Table 6 below.

Table 6. *Pre- and Post-test Differences in Wingate Test Variables within PLYO Training Group*

	N	Minimum	Maximum	Mean	SD
Pre-post Difference in An. Capacity	11	-0.09	0.79	0.1882	0.31723
Pre-post Difference in An. Power	11	-0.44	0.76	0.1855	0.47821
Pre-post Difference in Fatigue Index	11	-1.83	1.71	-0.2945	1.18573
Pre-post Difference in Weight	11	-11.20	3.70	-0.8182	4.30670
Valid N (listwise)	11				

Differences across the three tests are demonstrated in Figure 1 below.

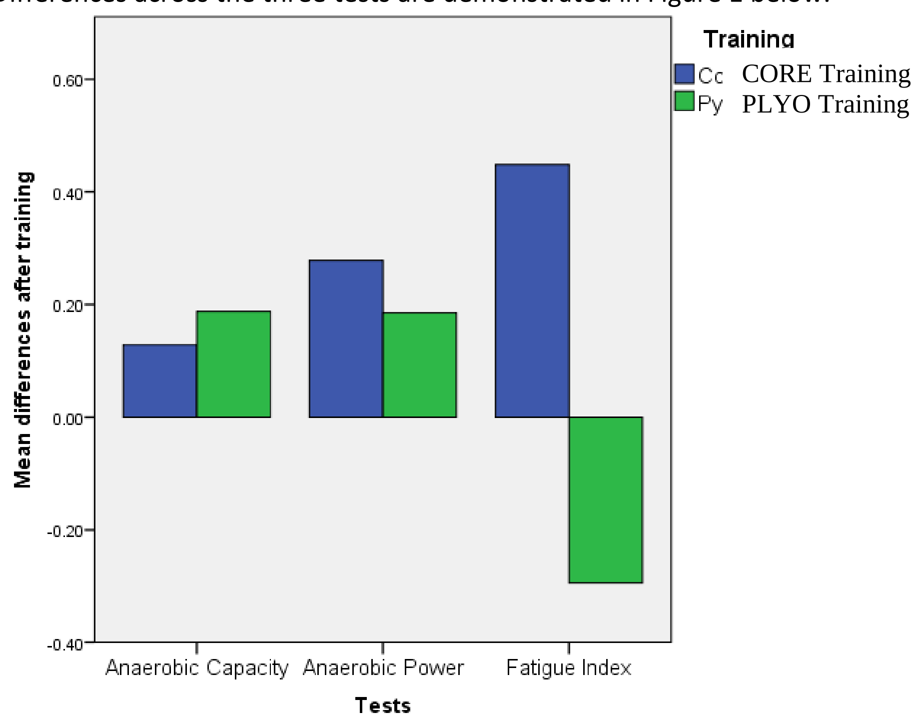

Figure 1: Average change in post-test scores by: test and training method

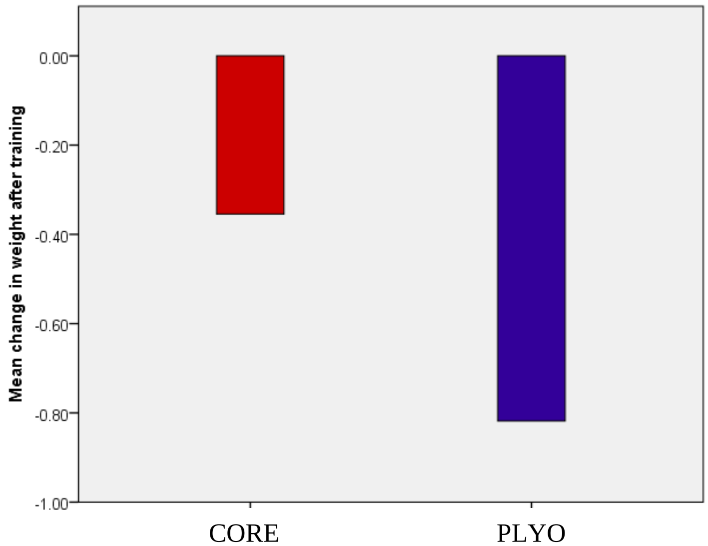

Figure 2. Average change in weight post-test by: training method.

Sex Differences

Upon a closer examination of differences between males and females on the types of training among the current participants. For the Core Training Group, females had higher mean differences in Anaerobic Power and Fatigue Index and a greater average weight change than males (see Tables 8 and 9).

Table 7. *Pre- and Post-test Differences in Wingate Test Variables within Females in the CORE Training Group*

	N	Minimum	Maximum	Mean	SD
Pre-post Difference in An. Capacity	6	-0.29	0.64	0.1167	0.35081
Pre-post Difference in An. Power	6	-1.01	2.22	0.3850	1.04550
Pre-post Difference in Fatigue Index	6	-2.53	5.05	0.6917	2.55613
Pre-post Difference in Weight	6	-6.60	4.20	-1.1200	4.43926
Valid N (listwise)	6				

Table 8. *Pre- and Post-test Differences in Wingate Test Variables within Male Participants in the CORE Training Group*

	N	Minimum	Maximum	Mean	SD
Pre-post Difference in An. Capacity	6	-0.50	0.53	0.1400	0.39309
Pre-post Difference in An. Power	6	-1.10	1.43	0.1717	0.97352
Pre-post Difference in Fatigue Index	6	-4.35	4.41	0.2050	3.47184
Pre-post Difference in Weight	6	-6.90	8.90	0.2833	5.56755
Valid N (listwise)	6				

For the PLYO group, females had little change in Anaerobic Capacity and Anaerobic Power, but had a decrease in the Fatigue Index, and a greater average weight change, losing 0.9286 pounds. In contrast, males experienced a mean increase in Anaerobic Capacity and Anaerobic Power but minimal change in Fatigue Index with an average weight loss of 0.625 pounds (see Tables 10 and 11 below).

Table 9. *Pre- and Post-test Differences in Wingate Test Variables within Females in the PLYO Training Group*

	N	Minimum	Maximum	Mean	SD
Pre-post Difference in An. Capacity	7	-0.09	0.36	0.0857	0.1603
Pre-post Difference in An. Power	7	-0.44	0.76	0.0686	0.4368
Pre-post Difference in Fatigue Index	7	-1.83	1.34	-0.4514	1.1308
Pre-post Difference in Weight	7	-3.70	3.70	-0.9286	2.4026
Valid N (listwise)	7				

Table 10. *Pre- and Post-test Differences in Wingate Test Variables within Males in the PLYO Training Group*

	N	Minimum	Maximum	Mean	SD
Pre-post Difference in An. Capacity	4	-0.06	0.79	0.3675	0.4655
Pre-post Difference in An. Power	4	-0.42	0.71	0.3900	0.5413
Pre-post Difference in Fatigue Index	4	-1.68	1.71	-0.0200	1.4040
Pre-post Difference in Weight	4	-11.20	3.40	-0.6250	7.0854
Valid N (listwise)	4				

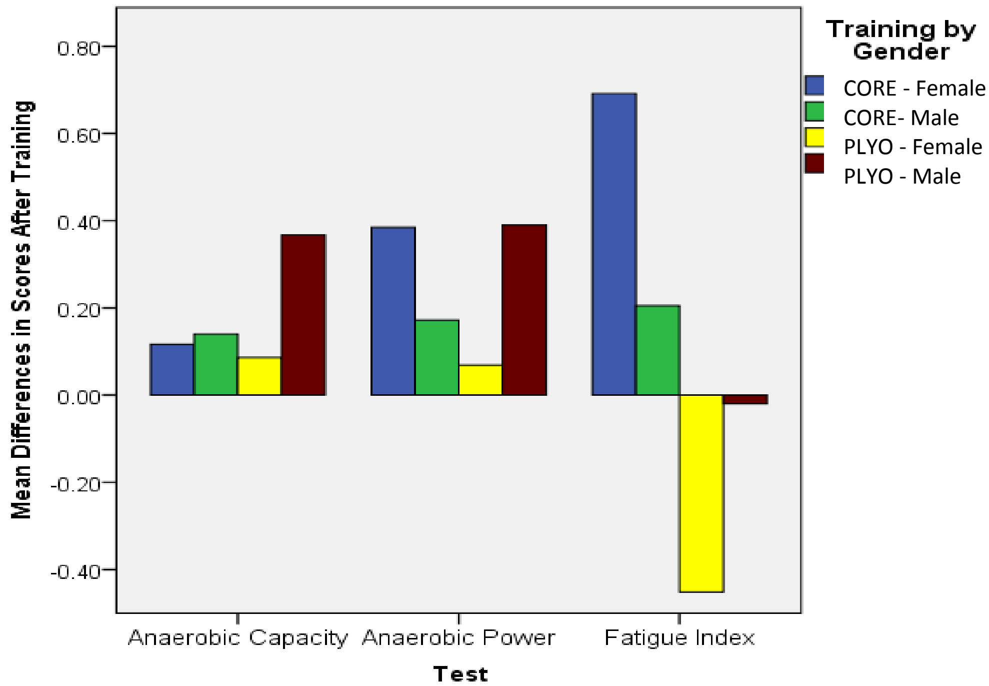

Figure 3. Average change in test scores after training by: test, gender, and training method.

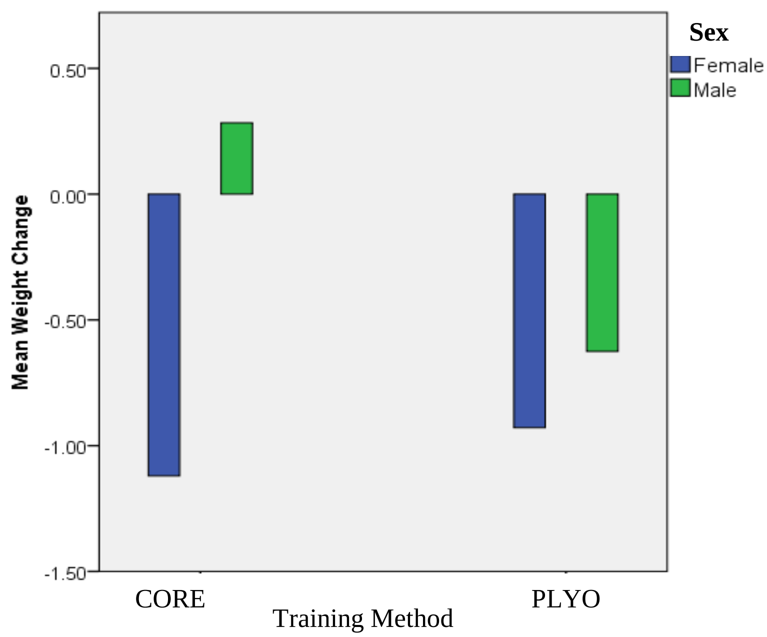

Figure 4. Average change in weight after training by: gender and training method.

Discussion

The purpose of this study was to determine if an explosive training intervention, utilizing plyometric and sprint training modalities, applied once per week would have an effect on Wingate measures of power after 12 weeks. The experimental group participated in a sprinting and plyometric program while the comparison group performed core and hip-stability exercises. A control group was not used within the study because the researcher wanted to ensure that time spent training was matched for volume between the two groups. This way, adaptations resulting from the intervention could not be attributed to simply more time spent on training.

All training sessions took place under the direction of a trained researcher to ensure a consistent manner of delivery was achieved and proper execution of exercises took place. A progressive overload method was used in determining the amount of training both the comparison and experimental groups took part in. Participants were also undergoing programmed endurance training of at least four to five times per week as part of a Marathon Training class (University of Minnesota, PE 1262) and elected to participate in the current study.

This investigation looked at a quantitative analysis with respect to the pre- and post-test results both *between* the CORE and PLYO groups, as well as *within* participant differences. This section will discuss the results in relation to past research, the implications that resulted from the present findings, as well as the limitations in research and the potential for future research opportunities.

Comparisons with Previous Research

Training Interventions and the Effects on Measures of Power

This is the only study to date that has looked at a combined plyometric and sprinting training intervention in relation to measures of Anaerobic Capacity, Power and Fatigue Index as determined by the Wingate test. The current study utilized an intervention only once per week for twelve weeks. Only one other study has looked at plyometric or sprinting interventions that are only once per week, but their duration was for seven weeks (Villarreal et al., 2008). Though Villarreal et al. (2008) showed that a once-a-week intervention involving both sprinting and plyometric exercises is enough time under task to achieve performance outcomes, though non-significant ones. However their subject pool consisted of recreational athletes with no previous plyometric training experience leading to the conclusion that a novel stimulus can lead to performance improvements when applied consistently for a length of time.

Mihalik, Libby, Battaglini, and McMurray (2008) looked at training regimen of twice a week for four weeks and found that after only three weeks, significant improvements ($p<0.0001$) in vertical jump height was observed. In comparison, the current study did not find any significant results while matched for training volume but not for time, concluding that one training session per week is not sufficient for making significant improvements in power outcomes measured via the Wingate test.

Most studies involve a higher volume of training such as two or more per week for four to nine weeks that has found data to indicate significant improvement in running economy and other performance measures like Vertical Jump, sprinting events, and test outcomes in both power and speed (Chimera et al., 2004; Dodd & Alvar, 2007; Lockie et al., 2012; Markovic et al., 2007; Paavolainen et al., 1999; Sankey et al., 2008; Saunders et al., 2006; Spurrs et al., 2003; Turner et al., 2003).

Training Interventions and the Effects on Measures of Power

Implications from Current Findings

Though the current study did not show significance in any pre- to post-test measures, all increased on average regardless of intervention group. This could be due to several factors including participation in the Marathon training class and various methods used throughout training, like interval workouts or hill sequences (See Appendix B). It could also be due to resistance load differences based on the weight changes detailed in the results.

Males and females within both groups on average lost weight from the beginning of the study to its conclusion. Since resistance load on the Wingate is determined by a percentage of body weight (kg), depending on the composition of that weight loss, could potentially help us understand average increases in performance measures regardless of intervention group. Another possible explanation could just be familiarization with testing protocol and the ability to mentally prepare for the Wingate protocol.

When comparing results between groups, the CORE group showed an average *increase* Fatigue Index whereas the PLYO group showed an average *decrease*. The Fatigue Index is a measure of power output percentage drop from the highest to lowest wattage over the duration of the 30 second test. Therefore a *decrease* in FI is an improvement in performance, indicating that subjects were able to maintain maximal power output for a longer amount of time. These findings are consistent with what was hoped in the initial hypothesis and study design. Although the results aren't significant, the F-statistic suggests that if power were increased by means of a larger subject population, statistical significance may be reached.

Our subject population is somewhat novel in the instance that they are already involved in a high volume of endurance training. In congruence with the present study, a partner study is looking at improvements in running economy and force plate data to determine if a once a week explosive training intervention influences positive performance changes. However, given our subjects are primarily endurance trained, the current study may have implications for sports that have a major endurance component, as well as explosive components, like soccer, lacrosse, basketball and hockey.

Due to the subject population spending more time training within an oxidative energy system, perhaps a once per week session of an explosive training intervention using sprinting and plyometrics may not have been enough to develop major anaerobic changes within the subjects' musculature. Given the high genetic component to muscle fiber distribution and the interplay of how Type I, Type IIa and IIx interact with one another, physiological adaptation may require more time under task specifically training within the anaerobic (phosphocreatine and lactate) energy systems (Crowther et al., 2002; Putman et al., 2004). Therefore, any indication of Type IIa muscle fiber transition to either a higher power capability through plyometrics versus a higher endurance capacity through extensive endurance training, leads to the conclusion that aerobic training techniques may negate anaerobic ones.

However, this may give us insight into sports that require athletes to do a high amount of aerobic conditioning and may not spend as much time on explosive speed or anaerobic training components. A more aerobically trained athlete's anaerobic capacity would therefore not be as developed and repeated sprints would diminish in speed and intensity when performed over a period of time as compared to an athlete more time spent conditioning within the Phosphocreatine or Lactate System.

Limitations within the Research

Sample size was fairly low in power, thus results may have been different if sample size were larger. However, given the voluntary nature of recruitment, and class participants already undergoing a high volume of training, it is unlikely research participation would increase within the same type of population.

Also, as part of the academic school year, participants had spring break throughout the course of a week during the study time frame. They were trusted with self-motivated training during their week off and compliance was not monitored. Also, on average, participants missed *at least* one other training session throughout the course of the study, decreasing their total time spent training in regards to the intervention groups.

Future Opportunities for Research

Increased time spent training within anaerobic systems, by increasing the number of sessions per week, the volume of exercise sets or by adding more exercises, may increase anaerobic capacity on a more pronounced level. Also, by changing our sample population or using a different population with fewer endurance training requirements, may have also made an impact on our performance outcomes.

Conclusion

Although the current study did not produce any significant results, valuable information came out of the test outcomes in terms of understanding how much training is necessary for greater changes in performance. This research lends to the conclusion that one session of plyometric and sprinting training is insufficient in drastically enhancing measures of power via the Wingate Test. Once per week anaerobic sessions are not adequate for physiological development of the anaerobic energy system within a novice marathon running population. Therefore more time spent training is needed to reach the desired training outcomes depending on an athlete's needs.

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Appendix A

CONSENT FORM

Effect of Plyometric vs. Core Training on Marathon Training, Running Economy, and Performance

You are invited to participate in a research study of the effect of plyometric versus core training on marathon training, running economy, and performance. You were selected as a possible participant because you are enrolled in the University of Minnesota course, PE 1262: Marathon Training. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This student research study is being conducted by Chris Lundstrom, Ph.D. student, along with Morgan Betker, M.S. student, and Dr. Stacy Ingraham, all from the University of Minnesota-Twin Cities School of Kinesiology. It is funded by TC Running Company, which will provide gift certificates of $100 or less that will be distributed by random drawing at the conclusion of the study. The study is completely optional, and has no bearing on grading or participation in PE 1262.

Study Purpose

The purpose of the study is to determine the effect of two different 12-week training programs (plyometric versus core training) on recreational runners training for a marathon. Differences between the two groups will be looked at for all of the following: Sprinting and jumping ability, running economy, two-mile and marathon finish time, muscle damage, and self-reported injury and soreness.

Study Procedures

Participants will be placed in either a core or plyometric training group by chance. The core program will consist of abdominal, back and hip exercises, such as crunches and planks. The plyometric program will consist of sprinting and jumping exercises such as hops and 50 meter sprints. The training involves one session of 15-20 minutes per week, for 12 weeks. The training for both groups will begin with basic exercises and become more challenging over the 12 weeks. The exercises are short in duration. The exercise intensity is moderate to high.

Before and after the 12 weeks of training, a number of tests will be done:

- Anaerobic field tests:
    - One maximal effort sprint for the each of the following: 60-m run, 200-m run, and flying 30-m run (a 30-m sprint with 20-m to build up speed). Sprints will be done on the indoor track and timed by researchers.
    - Three maximal effort jumps of each of the following: standing long jump and 10-bound test (alternate leg jumps for maximal distance). The 10-bound test

will be done on the indoor track, and the standing long jump will be done into a sand landing pit at the indoor track.
  - Rest between tests will be at least one minute between attempts, and at least 3 minutes between tests.
- Anaerobic lab tests:
  - Three maximal vertical jumps, starting from both a squatting position and from a standing position. This involves standing on a force plate and jumping and reaching as high as possible for each jump.
  - A Wingate cycle test on a stationary bike. This involves a short warm-up, followed by a maximal 30 second effort.
- Running economy: A 33-minute run on a treadmill. The pace will begin at a low intensity level and get faster over six stages, finishing at a moderately hard pace (approximately 10-km race pace). This involves wearing a facemask in order to measure oxygen use.
- Blood sample: Less than 1/4 teaspoon of blood will be taken three times during the study. This involves sticking a fingertip to pierce the skin and gathering blood. The blood sample will be tested for creatine kinase, which is a marker of muscle damage. The first sample will be taken prior to the start of training. The second will in the 1-2 days after a long run of approximately 20 miles (done as part of PE 1262 Marathon Training). The final sample will be collected 1-2 days after completing the marathon run.
- Training log data: Training logs used for PE 1262 will be examined after the study to assess training days missed due to injury (or other reasons), comments on pain/injury, soreness, preparedness to run, and rate of perceived exertion during select runs.
- Running performance: The 2-mile time-trials and the marathon will be done as part of PE 1262. Records of those performances will be used for data analysis.

Study timeline:

Event	**Estimated Time Commitment**	**Start Date**	**End Date**
Enrollment	30 min.	22-Jan	3-Feb
Field pre-testing	45 min.	27-Jan	1-Feb
Lab pre-testing	75 min	29-Jan	4-Feb
Training intervention	15-20 min./week	5-Feb	23-Apr
Post-run blood draw	15 min.	31-Mar	1-Apr
Field post-testing	45 min.	23-Apr	28-Apr
Lab post-testing	60 min	26-Apr	30-Apr
Post-marathon blood draw	15 min.	5-May	6-May

Risks of Study Participation

Certain changes can occur during the testing or training. Muscular soreness and stiffness are common effects of muscular strengthening exercises such as core and plyometric training. Other, less common symptoms that may occur during training or testing include abnormal blood pressure, fainting, irregular, fast or slow heart rhythm, and in rare instances, heart attack, stroke, or death. Every effort will be made to minimize these risks by evaluation of preliminary information relating to your health and fitness (gathered as part of PE 1262 requirements) and by careful observation during exercise and testing. Emergency equipment and trained personnel are available to deal with unusual situations that may arise.

As part of enrollment in PE 1262, you are expected to report certain information about your health. Health-related information will be reviewed by Dr. Stacy Ingraham, and will not be shared with research staff. If Dr. Ingraham is informed of a health issue that makes your participation in part or all of this study inadvisable, she will provide that information to you and note your health condition in a secure file. She will share your condition with the PI only by participant number. You will be advised to stop participating in any activity that may be detrimental to your health, given the reported condition. The Study Coordinator will be informed of the parts of the study that you are advised to not participate in, but the details of your condition will not be shared.

You may choose not to participate in any part of the training or testing due to pain, discomfort, or any other reason, without being removed from the study. You may choose to stop participation in the study at any time, and for any reason.

To protect against the risk that participation in this study will have any influence on grading for PE 1262, the instructor responsible for grading, Chris Lundstrom, will not have access to a list of participants until after final grades have been submitted. Scheduling for testing and training sessions will be done by Morgan Betker. You may request that Chris Lundstrom not be present at either the testing or training sessions, to ensure that no evaluation is being done that could influence grading. All data including missed sessions of training or testing and reported health information will be recorded by a participant ID number in order to protect the confidentiality of participants.

Benefits of Study Participation

There is no direct benefit to subjects who participate in this research. This training intervention and testing may provide insight into your response to muscular strengthening exercises and to running at a range of sub-maximal intensities. This may allow you to tailor your training and racing according to your own physiological responses.

Study Costs/Compensation

There are no costs associated with participating in this study. There is no payment for participation. Participants will be eligible for a random drawing for gift certificates of no more than $100 provided by the study sponsor, TC Running Company.

Research Related Injury

In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company. If you think that you have suffered a research related injury, let the researchers know right away.

Confidentiality

The records of this study will be kept private. In any publications or presentations, we will not include any information that will make it possible to identify you as a subject. Your record for the study may, however, be reviewed by departments at the University with appropriate regulatory oversight. Study data will be stored and communicated between researchers only by participant number, and will not reveal your identity. To these extents, confidentiality is not absolute. Study data will be encrypted according to current University policy for protection of confidentiality.

Voluntary Nature of the Study

Participation in this study is voluntary. Your decision whether or not to participate in this study will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Contacts and Questions

The researchers conducting this study are Chris Lundstrom, Morgan Betker, and Stacy Ingraham. You may ask any questions you have now, or if you have questions later, **you are encouraged to** contact them:

Chris Lundstrom
Primary Investigator
lund0982@umn.edu
612-381-7970

Morgan Betker
Co-Investigator and Study Coordinator
betke015@umn.edu
563-210-2543

Dr. Stacy Ingraham
Co-Investigator and Advisor
ingra013@umn.edu
612-626-0067

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you are encouraged to contact the Fairview Research Helpline at telephone number 612-672-7692 or toll free at 866-508-6961. You may also contact this office in writing or in person at *Fairview Research Administration, 2344 Energy Park Drive, St. Paul, MN 55108.*

You will be given a copy of this form to keep for your records.

Statement of Consent

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature of Subject___________________________________ Date__________________

Signature of Person
Obtaining Consent_____________________________________ Date__________________

Appendix B

Marathon Running Training Plans

Plan A

WEEK	MON	TUE	WED	THU	FRI	SAT	SUN
1	1/20	1/21	1/22	1/23	1/24	1/25	1/26
	OFF	20 min	First day of class!!! 2 mile TT	OFF	20 min	OFF	6 miles
2	1/27	1/28	1/29	1/30	1/31	2/1	2/2
	OFF	30 min	30 min run w/ drills + accels	OFF	30 min	OFF	8 miles
3	2/3	2/4	2/5	2/6	2/7	2/8	2/9
	OFF	30 min	20 min LT (+warm/cool)	OFF	30 min	OFF	10 miles
4	2/10	2/11	2/12	2/13	2/14	2/15	2/16
	OFF	30 min	Hills	OFF	30 min	OFF	12 miles
5	2/17	2/18	2/19	2/20	2/21	2/22	2/23
	OFF	20 min	10, 10, 5 min LT w/ 2 min rec.	OFF	30 min	OFF	14 miles
6	2/24	2/25	2/26	2/27	2/28	3/1	3/2
	OFF	30 min	Hills	OFF	40 min	OFF	90 min.
7	3/3	3/4	3/5	3/6	3/7	3/8	3/9
	OFF	30 min	6x5 min LT w/ 1 min rec.	OFF	20 min	OFF	16 miles
8	3/10	3/11	3/12	3/13	3/14	3/15	3/16
	OFF	30 min	Hills	OFF	40 min	Spring Break OFF	90 min. on own
9	3/17	3/18	3/19	3/20	3/21	3/22	3/23
	OFF	30 min	40 min w/ 20 min LT	OFF	30 min	OFF	14 miles on own
10	3/24	3/25	3/26	3/27	3/28	3/29	3/30
	OFF	30 min	3x10 min LT	OFF	20 min	OFF	18 miles
11	3/31	4/1	4/2	4/3	4/4	4/5	4/6
	OFF	30 min	30 min fartlek	OFF	30 min	OFF	**PE 1262 Half Marathon**
12	4/7	4/8	4/9	4/10	4/11	4/12	4/13
	OFF	20 min	2x15 min LT	OFF	40 min	OFF	20 miles

13	4/14	4/15	4/16	4/17	4/18	4/19	4/20
	OFF	30 min	2 mile TT	OFF	30 min	OFF	2:00
14	4/21	4/22	4/23	4/24	4/25	4/26	4/27
	OFF	30 min	6x3 min on/2 min off	OFF	30 min	OFF	70 min.
15	4/28	4/29	4/30	5/1	5/2	5/3	5/4
	OFF	20 min	20 min	OFF	15 min	OFF	**Eau Claire Marathon**

Plan B

WEEK	**MON**	**TUE**	**WED**	**THU**	**FRI**	**SAT**	**SUN**
1	1/20	1/21	1/22	1/23	1/24	1/25	1/26
	OFF	30 min	First day of class!!! 2 mile TT	OFF	30 min	20 min	8 miles
2	1/27	1/28	1/29	1/30	1/31	2/1	2/2
	OFF	30 min	40 min run w/ drills + accels	OFF	40 min	20 min	10 miles
3	2/3	2/4	2/5	2/6	2/7	2/8	2/9
	OFF	30 min	20 min LT (+warm/cool)	OFF	40 min	20 min	12 miles
4	2/10	2/11	2/12	2/13	2/14	2/15	2/16
	OFF	35 min	Hills	OFF	40 min	20 min	14 miles
5	2/17	2/18	2/19	2/20	2/21	2/22	2/23
	OFF	35 min	10, 10, 5 min LT w/ 2 min rec.	OFF	40 min	20 min	16 miles
6	2/24	2/25	2/26	2/27	2/28	3/1	3/2
	OFF	40 min	Hills	OFF	40 min	20 min	90 min.
7	3/3	3/4	3/5	3/6	3/7	3/8	3/9
	OFF	40 min	6x5 min LT w/ 1 min rec.	OFF	30 min	10 min	18 miles
8	3/10	3/11	3/12	3/13	3/14	3/15	3/16
	OFF	45 min	Hills	OFF	40 min	SPRING BREAK 20 min	90 min. on own
9	3/17	3/18	3/19	3/20	3/21	3/22	3/23
	OFF	45 min	45 min w/ 20 min LT	OFF	50 min	20 min	16 miles on own

10	3/24	3/25	3/26	3/27	3/28	3/29	3/30
	OFF	50 min	3x10 min LT	OFF	40 min	15 min	20 miles
11	3/31	4/1	4/2	4/3	4/4	4/5	4/6
	OFF	50 min	30 min fartlek	OFF	40 min	20 min	**PE 1262 Half Marathon**
12	4/7	4/8	4/9	4/10	4/11	4/12	4/13
	OFF	40 min	2x15 min LT	OFF	45 min	20 min	20 miles
13	4/14	4/15	4/16	4/17	4/18	4/19	4/20
	OFF	40 min	2 mile test #2	OFF	40 min	20 min	2:00
14	4/21	4/22	4/23	4/24	4/25	4/26	4/27
	OFF	40 min run	6x3 min on/2 min off	OFF	30 min	20 min	80 min.
15	4/28	4/29	4/30	5/1	5/2	5/3	5/4
	OFF	20 min	30 min	OFF	15 min	OFF	**Eau Claire Marathon**

Appendix C

Pre-testing Instructions

Hello Participants!

Thanks again for agreeing to participate in this amazing study!! Please read the information below so that you are prepared for your testing sessions.

Pre-Testing Instructions:

Field testing is done in the University Fieldhouse. Meet at the indoor track. Lab testing is done at the Human and Sport Performance lab, in University Rec. Center 27A (same location as you did the VO_{2MAX} test).

Be sure that you are rested. If you exercise the day before the test, be sure it is of light to moderate intensity an relatively short duration. You should not exercise within 12 hours of your test, and you should not do heavy or prolonged exercise in the 48 hours before your test.

In the 24-48 hours prior to your test, eat and drink as you would in preparation for a hard exercise session. Wear clothing that is comfortable for running in warm weather and footwear that is similar to what you typically run in.

Additional Preparation and Instructions:

Upon your arrival, you will check in, fill out a brief questionnaire, and you will have an opportunity to ask any questions that you may have. If you must cancel or reschedule your test, please do so at least 48 hours in advance. (contact Morgan Betker: betke015@umn.edu).

Please let me know if you have any questions,
Morgan Betker

Appendix D

Lab Testing Protocol

Schedule:

1) Check in participant, confirm participant number and record number on testing sheet
2) Height and weight (for RE and Wingate tests)
3) 5 min walk/jog. Start @ 4 mph and progress according to subject preference
4) Vertical Jump (3xVJ w/ Vertec, 3xCMJ on FP, 3xSJ on FP, up to 3xVJ w/ Vertec)
5) Running Economy Test
6) 5 minutes full recovery
7) Wingate Test

HEIGHT AND WEIGHT:

1) Subject should remove shoes for both height and weight
2) Extra layers of clothing should be removed for weight. Subject should wear what they will wear for running on the treadmill and for the Wingate test.

WARM-UP

1) Use either the Trackmaster or Incline Treadmill.
2) Begin with 1 minute at 4 mph, and increase either 1 mph per minute, or according to the subject's preferred warm-up pace.

VERTICAL JUMP

1) Subject should stand with heels flat and reaching arm fully extended.
2) Bottom of 6" (blue) tape mark should be moved to even with the tip of the furthest extended fingertip
3) Subject should take at least one submaximal practice jump, then be asked if they are ready to begin.
4) 3-6 jump attempts may be taken, with height vanes being cleared back to provide a goal for increasing on the next attempt. 3 jumps will be recorded, then force plate countermovement jumps (CMJ) and squat jumps (SJ) will be done. Additional attempts at increasing jump height on the Vertec may be taken after the force plate (FP) jumps.
5) No more attempts after failure to increase on two consecutive attempts, or after a maximum of 6 attempts.

RUNNING ECONOMY

1) Subject should be fitted with heart rate monitor and the watch should be checked to confirm consistent signal
2) Fan should be turned on and pointed at treadmill.
3) Lundstrom RE protocol should be edited according to individual's specific paces, via "Open…Exercise Device Protocol"
4) Find subject according MAR2014 ID#, and add visit
5) Enter height and weight from data sheet, and select Lundstrom RE for test protocol.
6) Click on GX

7) Review protocol (a 3 min. warm-up stage and six stages of 5 min. starting very easy and finishing at slightly slower (93%) than 2 mile pace. Elevation remains @ 1.0% throughout
8) Confirm that subject knows what to do if they need to stop for any reason (step on rails, or hit stop, or raise their right hand above their head). Inform them that it is best not to try to talk during the test, as it won't be understandable and may affect data.
9) Fit subject with mask and connect to Medgraphics cart.
10) Click start and confirm HRM and gas data analysis working with 1 minute of standing on the treadmill.
11) Click begin exercise and adjust treadmill to reflect appropriate paces throughout the course of the 33-minutes of exercise, monitoring data collection and subject throughout.
12) At the conclusion of the 33-minutes, slow the treadmill to 3.0 mph and ask subject to walk for 1 minute, or until heart rate has reduced to <60% MHR.
13) Stop treadmill, remove mask, and instruct subject to keep HRM on for Wingate test.

WINGATE

1) Allow 5 min. recovery after RE test, with access to fluids, bathroom.
2) After resting, have the subject warm up for three minutes using a MONARK bike.
    a. Adjust the seat height to five degrees of knee flexion at the bottom of their end-range of pedal motion
    b. Ensure there is no resistance load on the bike
    c. Instruct subject that their warm-up will consist of:
        i. Three minutes of continuous pedaling at a cadence of 65-75rpm
        ii. At the top of each minute, sprint for five seconds
    d. Post-warm-up, the subject will sit for three minutes of complete rest prior to the test.
3) Input Age, Sex, Height and Weight into the Velotron Software Program

4) Adjust Velotron seat height and handle bar length and height to accommodate subjects' anthropometrics.
5) Instruct the subject on what the test will consist of (detailed below) and that they must keep their rear-end on the seat at all times during the test.
    a. Have the subject start pedaling with a cadence of between 65-75 rpm.
    b. Start data collection while the subject keeps pedaling at this speed for 10 seconds.
    c. Instruct Subject to sprint as fast as possible, with no resistance for 3 seconds.
    d. The resistence load will drop immediately following their three second, unresisted sprint.
    e. Vigorously encourage the subject to continue pedaling as hard as they can for the remaining 30 seconds of the test
6) Recovery phase immediately following the test will be 2-3 minutes in length, with no resistance.

Appendix E

Plyo/Core Study Training Session Instructions

1) Check in each person for the day.
2) Tell participants what exercises they will be doing that day.
3) Before each exercise, demonstrate and allow sub-maximal practice.
4) Correct form to insure proper range of motion and execution of each exercise.
5) Plyo/Speed exercises to be done at high velocity, at or near max. effort, with a focus on **short contact times** for the jumps.
6) Core exercises should be done at low-to-moderate velocity, with a two second concentric phase, a brief hold, and a 2 second eccentric phase.
7) If anyone is unable or unwilling to complete any or all of the exercises for whatever reason, make a note of what they did and did not do, ask them why, and record any reported reasons.

Appendix F

Training Intervention Schedules

Explosive Intervention Exercise Schedule (PLYO)

CAT		SPR	SPR	SPR	SPR	HOR	HOR	HOR	HOR	HOR	VERT	VERT	VERT	VERT
Sess. #	Date	50-m Build	30-m Fly	60-m spr.	In-n-Out	Stand LJ	Alt. Leg Bound	S.Leg Fwd Hop	Lat. Cone Jumps	F/B Cone Jumps	Squat Jump	Split Scissor Jump	Depth Jump	Box Jump
1	5-Feb	2	2			1x10	2x10	1x8			1x10			
2	12-Feb			2	2				1x10	1x10		1x10	1x8	
3	19-Feb	3	3			2x8	2x15	1x12			2x8			
4	26-Feb			3	3				1x15	1x15		2x8	1x12	
5	5-Mar	3	3			2x10	2x20	2x10			2x10			
6	12-Mar			3	3				2x10	2x10		2x10	1x15	
7	19-Mar	4	4			2x15	3x15	2x12			2x15			
8	26-Mar			4	4				2x15	2x15		2x15		1x10
9	2-Apr	4	4			2x15	3x20	2x15			2x15			
10	9-Apr			4	4				2x20	2x20		2x15		1x15
11	16-Apr	3	3			1x20	2x20	1x20			1x20			
12	23-Apr			2	2				1x20	1x20		1x20		1x10
					(20-10-20-10-20)									

Core Stability Intervention Exercise Schedule (CORE)

CAT		ABS	ABS	ABS	ABS	BACK	BACK	BACK	BACK	HIP/GL	HIP/GL	HIP/GL	HIP/GL
Sess. #	Date	Crunch	Side crunch	Sit-ups	V-Sits	Super-man	Back-Ups	Plank	Side Plank	Fire Hydrants	Sw. Ball Adductors	Bridging	Bird Dog
1	5-Feb	1x20		1x20		1x20		30s		1x20		1x20	
2	12-Feb		1x20		1x20		1x10		30s		1x20		1x20
3	19-Feb	1x30		1x30		1x30		45s		1x30		1x30	
4	26-Feb		1x30		1x30		1x15		45s		1x30		1x30
5	5-Mar	2x20		2x20		2x20		60s		2x20		2x20	
6	12-Mar		2x20		2x20		2x10		60s		2x20		2x20
7	19-Mar	2x30		2x30		2x30		2x45s		2x30		2x30	
8	26-Mar		2x30		2x30		2x15		2x45s		2x30		2x30
9	2-Apr	3x30		3x30		3x30		2x60s		3x30		3x30	
10	9-Apr		3x30		3x30		3x15		2x60s		3x30		3x30
11	16-Apr	2x30		2x30		2x30		60s		2x30		2x30	
12	23-Apr		2x30		2x30		2x15		60s		2x30		2x30
												2 legged	
			per side						per side	per side			per side