

RESISTANCE TRAINING AND EFFECTS ON
DISTANCE RUNNING PERFORMANCE

By

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Abstract of Thesis

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Resistance Training and Effects on Distance Running Performance

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Resistance Training and Effects on Distance Running Performance

The purpose of this study was to investigate the effect that simultaneous resistance training and endurance training had on distance running performance through the retrospective analysis of the existing public information of the collegiate indoor and outdoor track and field seasons by male and female distance runners who experienced the changes in coaches, coaching philosophies, and training strategies at the University of Wisconsin-Whitewater from the 2009 through 2010 seasons. Fourteen male distance runners and eight female distance runners competed in the indoor track and field season, while eleven male distance runners and six female distance runners competed in the outdoor track and field season in both 2009 and 2010 at the University of Wisconsin – Whitewater. Publicly available track and field meet results were obtained and the best single performance across events was identified for each runner using the Scoring Tables of Athletics published by the International Association of Athletics Federations (IAAF). For the indoor seasons, IAAF scores for males improved by 22.31 ± 5.55 points from 2009 to 2010, which approached statistical significance ($p = 0.0510$), while IAAF scores for females declined by 19.50 ± 1.35 from 2009 to 2010, which was statistically significant ($p = 0.0462$). For the outdoor seasons, IAAF scores for males improved by 70.00 ± 3.95 , which was statistically significant ($p = 0.0026$), while IAAF scores for females declined by 11.00 ± 15.74 , which was not statistically significant ($p = 0.3382$). While the results were not overwhelming, the results do suggest that adding a resistance

training program to a distance training program can improve the athletes overall running performance.

CHAPTER I

INTRODUCTION

Coaches and strength and conditioning professionals seem to place a low priority on resistance training when it comes to training distance runners. This is due to a number of factors, including the fear of bulking up the distance runner on the coaches end and the lack of commitment to designing the resistance training program from the strength and conditioning professional because his or her top priority is to devote the majority of their efforts in sports such as football and basketball.

In sports that depend almost exclusively on one of the three energy sources, long-term intensive training of a second energy source may take away from development of the primary energy source. For example, distance runners depend heavily on the aerobic energy system, and the extensive training of the adenosine triphosphate phosphocreatine energy system using resistance training may compromise the development of the aerobic energy source over long training periods (i.e., years). For the same reason, athletes who are highly dependent on strength/power may not want to heavily train the oxygen energy source. Whether this is due to overtraining resulting from the high volume and intensity necessary to train simultaneously for endurance and strength, or to some underlying physiological mechanism, is still unknown (Fleck & Kraemer, 2004).

Distance running performance is most commonly thought to be enhanced only by aerobic activities. However, research studies have shown that anaerobic factors may play

an important role in distance running performance. Even though aerobic energy requirements play a predominant role in endurance events, anaerobic forms of training in a distance runner's program may have some benefits on endurance performance characteristics such as maximal oxygen consumption, lactate threshold, and running economy. Most coaches and distance runners share the same ideology that improvements in these areas are primarily achieved through endurance training.

MacDougall et al. (1979) noted a decrease in mitochondrial volume density in the triceps muscle after a high-intensity strength training program. Because mitochondria are the site of aerobic energy production, any decrease in the volume density of mitochondria could theoretically decrease the oxidative capacity of the muscle. Thus, based on the results of this study, many distance runners did not perform resistance training fearing that it will compromise their endurance capabilities. A decrease in mitochondrial density would appear to support this belief. What distance runners failed to recognize, however, was that resistance training offers other benefits, such as injury prevention and the mitigation of the overuse phenomenon. Protein being removed from the Type I and IIC muscle fibers with high-intensity endurance running may result in injury and decreased performance over the long term (Kraemer et al., 1995).

Simultaneous resistance training and aerobic training is still frowned upon by many coaches and athletes in the distance running community because of the idea that resistance training will waste needed energy for aerobic training and the fear of increased muscle mass, which could result in weight gain and limit range of motion in their running stride.

When integrating aerobic and anaerobic components into a training program, the most important factors are prioritization and compatibility of the components.

Resistance Training

Resistance training is a specialized method of conditioning that involves the progressive use of resistance to increase one's ability to exert or resist force (Fleck & Kraemer, 2004). Resistance training has been proven a safe and effective method of conditioning for athletes with various goals, abilities, and needs. Resistance training improves bone, muscle, tendon and ligament strength and toughness, improves joint function, reduces potential for injury, increases bone density, increases metabolism, and improves cardiac function. Increasing bone strength is especially important to distance running and the numerous cases of shin splints and stress fractures that occur throughout a runner's career.

Muscle strength increases the force exerted on the bones. Stronger forces of muscular contraction increase the mechanical stress on bone, and bone must subsequently increase in mass and strength to provide a sufficient support structure for the muscles. Thus, an increase in muscle strength or mass may result in a corresponding increase in bone mineral density (BMD), by an increase in the quantity of mineral deposited in a given area of bone (Fry, 1993; Karlsson, Johnell, & Obrandt, 1995). Inactivity or immobilization has the opposite effect on bone mass, resulting in a more rapid rate of loss of bone matrix and BMD. Numerous studies have shown a positive correlation between BMD and muscle strength and mass (Pocock et al., 1989; Wittich et al., 1998).

Resistance training programs that emphasize muscular endurance involve performing many repetitions - 12 or more - per set (Berger, 1972; Fleck, 2003; Fleck & Kraemer, 2004; Garhammer, 1986; Kraemer & Koziris, 1992; Lombardi, 1989; O'Shea, 1976; Stone, O'Bryant, Garhammer, McMillan, & Rozenek, 1982; Tesch, 1992; Tesch & Larson, 1982; Verhoshansky, 1976). Despite this relatively high repetition assignment, the overall volume-load is not necessarily inflated since the loads lifted are lighter and fewer sets are performed, commonly two to three per exercise (Kraemer & Koziris, 1992). A muscular endurance training program has very short rest periods, often less than 30 seconds. This restriction of the recovery time is purposeful; only a minimal amount of rest is allowed when light loads are being lifted for many repetitions. This type of program is designed to meet the guideline of the specificity principle for muscular endurance (Baechle & Earle, 2006). Short rest periods are characteristic of circuit training programs (Gettman & Pollock, 1981; Harman & Frykman, 1992) in which it is common to alternate exercises and limit rest period lengths to 30 seconds or less (Richardson, 1993; National Strength and Conditioning Association [NSCA], 1990; National Strength and Conditioning Association [NSCA], 1990).

A considerable amount of research has been carried out in relation to the effect of resistance training and endurance training in isolation have on exercise performance and associated physiological variables. In contrast, data describing the compatibility of these two training modes are relatively sparse. The majority of studies in the literature have utilized relatively untrained subjects to examine the physiological effects of simultaneous strength and endurance training (Baechle & Earle, 2006; Berger, 1962). However, few

data is available regarding the effects of simultaneous strength and endurance training that utilized previously active or fit individuals who are able to tolerate much higher intensity exercise training programs.

From the large body of concurrent strength and endurance training literature, it appears that distance runners or participants in endurance sports that require a significant amount of running appear to gain the most advantage from resistance training (Laursen, Chriswell, & Callaghan, 2005).

Running Speed

Distance running is quite simplistic: the athlete that runs the fastest over a given amount of distance wins the competition. Running speed is the product of stride rate and stride length. Although both stride rate and stride length are increased with increasing running speed, stride length is responsible for increasing speed up to 90% of an individual's maximum speed and, thereafter, the speed is only increased by increasing stride rate (Luhtanen, 1978; Mero, Komi, & Gregor, 1992; Weyand, Sternlight, Bellizzi, & Wright, 1991-1999). One might think, when does a distance runner ever sprint during their race? A long distance runner sprints to the finish of the race. The sprint at the end of a race is referred to as a "kick" and it usually occurs during the last 200-400 meters of a distance race. Cavanagh and Williams (2004) found the most economical stride length of a group of runners was close to that which was freely chosen. The ground contact phase is the only phase during the running cycle in which a runner can produce force and influence stride length and running speed.

Functional and mechanical requirements during stance are reflected in the characteristics of the ground reaction force. It has been shown that vertical and horizontal components of ground reaction forces increase with increasing running speed (Kyröläinen, Belli, & Komi, 2001; Mero et al., 1992; Weyand et al., 1991-1999). Weyand et al. (1991-1999) concluded that runners reach faster top speeds by applying greater support forces to the ground and not by more rapid leg movements. The critical point in maximal sprint running is the change in running speed during the ground contact phase. The horizontal braking force and braking time as well as the horizontal distance between the first contact point and the center of gravity of the body at touchdown should be very small to avoid loss of speed during the braking phase of ground contact (Mero & Komi, 1986).

The amount of energy used to run a constant distance is nearly the same whether it is run at top speed or at leisure pace. The results of Kram and Taylor (1990) suggest that, primarily, the cost of supporting the body weight and the time course generating this force determines the cost of running. Therefore, a long ground contact phase and great deceleration of horizontal speed during a braking phase of the ground contact could be considered wasteful in terms of the metabolic energy requirements. A successful endurance runner is characterized by less vertical oscillation (Gregor & Kirkendall, 1978), longer strides (Cavanagh & Williams, 1982), shorter ground contact times (Paavolainen, Nummela, & Rusko, 1999), less change in speed during the ground contact (Kaneko, Ito, Fuchimoto, Shishikura, & Toyooka, 1985), and lower first peak in the

vertical component of the ground reaction force, associated with a tendency to have smaller antero-posterior peak forces (Williams & Cavanagh, 1987).

In a well controlled study, Heise and Martin (2001) showed that less economical runners exhibited greater total and net vertical impulse, indicating wasteful vertical motion. It is a well known fact that elite sprint runners have a higher top running speed and a lower running economy than elite distance runners. Although there is a discrepancy between the high neuromuscular capacity to produce force and running economy, some previous studies have shown that the explosive type strength training can be used to improve both maximal power output and running economy (Johnston, Quinn, Kertzer, & Vroman, 1997).

Adaptations to Aerobic Endurance Training

Aerobic endurance training results in several changes in cardiovascular function, including increased maximal cardiac output, increased stroke volume, and reduced heart rate at rest and during submaximal exercise. The most significant change in cardiovascular function with long endurance training is the increase in maximal cardiac output, resulting primarily from improved stroke volume (Baechle & Earle, 2008).

Ventilatory adaptations from training include increased tidal volume and breathing frequency with maximal exercise. With submaximal activity, breathing frequency is often reduced and tidal volume is increased. Ventilatory adaptations result from local, neural, or chemical adaptations in the specific muscles trained through exercise (Beck & Johnson, 1998).

Nervous system adaptations play a significant role in the early stages of aerobic endurance training (Sale, 1987). With continuous aerobic training, the athlete will produce a more efficient locomotion during running with lower energy expenditure.

One of the fundamental adaptive responses to aerobic training is an increase in the aerobic capacity of the trained musculature. This adaptation allows the athlete to perform a given absolute intensity of exercise with greater ease. More impressively, after training, an athlete can exercise at a greater relative intensity of a now higher maximal aerobic power. This adaptation occurs as a result of glycogen sparing and increase fat utilization within the muscle, which prolongs performance (Holloszy, 1998).

The increase in muscle mass is almost impossible when high-intensity aerobic endurance exercise is incorporated in a distance runner's training program. High-intensity aerobic endurance exercise can cause a dramatic catabolic tissue response, and increases in testosterone may be related to the need for protein synthesis to keep up with protein loss (Kraemer et al., 1995; Tapperman, 1980; Terjung, 1979). Despite increased testosterone, hypertrophy does not typically take place with aerobic endurance training (Kraemer et al., 1995). In fact, oxidative stress may actually promote a decrease in muscle fiber size in order to optimize oxygen transport into the cell (Kraemer et al., 1995). Without the proper exercise stimulus, the cellular mechanisms that mediate muscle fiber growth are not activated to the extent that hypertrophy occurs.

Aerobic training has been shown to increase bone and connective tissue. Aerobic programs that are the most successful in stimulating bone growth involve more intense physical activities. The key to the success of aerobic exercise in stimulating new bone

formation is that the activity be significantly more intense than the normal daily activities the athlete typically engages in. The intensity of the activity must systematically increase in order to continually overload the bone. Bone responds to the magnitude and rate of external loading. Therefore, to enhance the stimulus to the musculoskeletal system, it is also necessary to increase the rate of limb movement (Baechle & Earle, 2008). Using interval training techniques is one method of providing the benefits associated with aerobic exercise (Frost, 1997; Wittich et al., 1998).

The extent to which tendons, ligaments and cartilage grow and become stronger is proportional to the intensity of the exercise stimulus. Animal studies to evaluate the potential negative effects of aerobic exercise on cartilage have shown encouraging results. Long-term adherence to treadmill exercise in guinea pigs thickens the cartilage and increases the number of cells (Saaf, 1950). Running studies using dogs as subjects demonstrated that a moderate running program (2.5 miles per day, five days per week for 40 weeks) increased cartilage thickness and stimulated remodeling of bone tissue. It was also found that more strenuous running (increased to 12.5 miles per session) decreased cartilage thickness; but even running 25 miles per session for one year, or weighted running (using jackets weighting 130% of the animals weight) of 2.5 miles five days per week for 550 weeks, did not cause degenerative joint disease (Buckwalter, 1995).

Adaptations to Anaerobic Training

The human body is a living organism that adapts to external and internal stressors. When the body experiences a new stress or a more intense stress than previously applied (e.g., lifting heavier resistance training loads or a greater load volume), the first response

is the “shock” or “alarm phase”. This phase may last several days or several weeks, during which the athlete may experience excessive soreness, stiffness, and a temporary drop in performance (Baechle & Earle, 2008).

Next is the “resistance phase,” one in which the body adapts to the stimulus and returns to more normal functioning. In this phase, the body is able to demonstrate its ability to withstand the stress, an attribute that may manifest itself for an extended period depending on the health and training status of the athlete. Here, the athlete relies on neurological adaptations to continue training while the muscle tissue adapts by making various biochemical, structural, and mechanical adjustments that lead to increased performance (Brahm, Mallmin, Michaelsson, Strom, & Ljunghall, 1998). This phase of adaptation is sometimes called supercompensation.

However, if the stress persists for an extended time, the exhaustion phase is reached. Some of the same symptoms experienced during the alarm phase reappear (fatigue, soreness, etc.), and the athlete loses the ability to adapt to the stressor. Staleness, overtraining, and other maladaptations may occur when there is no training variety or when the training stress is too great (Baechle & Earle, 2008).

There are ways to avoid the exhaustion phase by creating a periodized training program. Periodization of training refers to planned changes in the acute training program variable of exercise order, exercise choice, number of sets, number of repetitions per set, rest periods between sets and exercises, exercise intensity, and number of training sessions per day in an attempt to bring about continued and optimal aerobic and anaerobic gains (Baechle & Earle, 2008).

The main goals of periodization training are optimizing training adaptations during short periods of time (e.g., weeks and/or months) as well as long periods of time (e.g., and/or years, an entire athletic career). Some periodized plans also have as a goal to peak physical performance at a particular point in time, such as a major competition (Fleck & Kraemer, 2004).

Adaptations to exercise are considered to be primarily dependent on the specific type of training performed. On a performance basis, endurance training, which represents a type of exercise at one extreme of physical activity, increases the capacity to sustain repetitive high intensity, low-resistance exercise, such as cycling or running. Strength training, which represents a type of exercise at the other extreme of physical activity, increases the capacity to perform high-intensity, high-resistance exercise of various repetitions, such as weight lifting (Fleck, 1988).

Acute and chronic anaerobic training has a significant impact on cardiovascular and respiratory function. Resistance training can benefit the cardiovascular system, but in a manner different from conventional aerobic endurance training (Fleck, 1988). Improved ability of the heart, lungs, and circulatory system to function under conditions of high pressure and force production can prepare the athlete's body for extreme competitive demands. An acute bout of anaerobic exercise significantly increases the cardiovascular responses. Heart rate, stroke volume, cardiac output, and blood pressure increase significantly during resistance exercise (Fleck, 2003).

Oxygen extraction is generally not improved with resistance training using heavy loads and low volume. It is enhanced to a greater extent with continuous aerobic exercise

or perhaps slightly with a resistance training program using high volume and short rest periods, such as strength endurance training (Fleck, 2003).

Explosive Plyometric Training

It is generally misunderstood that explosive strength qualities are important in power sports involving running, jumping, and other changes in speed or direction. There is a common misconception, however, that their role in aerobic endurance activities is minor. For example, since elite marathoners' running velocities are about half those achieved by sprinters (Hawley, 2000; Putnam & Kozey, 1989; Schmolinsky, 1993; Wilt, 1968; Wilt, 1973), explosive force output is often mistakenly believed to be insignificant. Ground contact times at intermediate running speeds tend to be longer than those at top speeds (0.2 seconds at 5-6m/s) (Hawley, 2000; Hochmuth, 1984; Putnam & Kozey, 1989; Schmolinsky, 1993; Stein, 1998; Tidow, 1990), but are significantly shorter than required for maximal force development.

Because running is an inherently ballistic activity, power, impulse, and reactive ability are important determinants of performance over any distance or duration. The value of explosive strength for long-distance aerobic endurance events becomes apparent when one considers the improvements that are achievable with modest increases in stride frequency, length, or efficiency (Jung, 2003; Saunders, Pyne, Telford, & Hawley, 2004).

One of the most interesting and undervalued forms of training for runners, proven to enhance economy, is strength work. This includes a special type of training known as plyometrics. Plyometrics invokes specific neural adaptations, such as an increased activation of motor units, with less muscle hypertrophy than typical heavy-resistance

strength training (Hakkinen, Komi, & Alen, 1985; Hakkinen, 1994; Sale, 1991). Strength training and plyometrics have both been shown to improve running performance and economy. They do so by taking advantage of something known as the stretch-shortening cycle (SSC).

The stretch-shortening cycle is an eccentric-concentric coupling phenomenon in which muscle-tendon complexes are rapidly and forcibly lengthened, or stretch loaded, and immediately shortened in a reactive or elastic manner. The stretch-shortening reflex involves three distinct phases. Phase one is the eccentric phase, which involves preloading the agonist muscle group. Phase two is the time between the eccentric and concentric phases and is termed the amortization or transition phase. Phase three is the the concentric phase and is the body's response to the eccentric and amortization phase. During running the eccentric phase begins at foot touchdown and continues until the movement ends. The amortization phase is the transition from eccentric to concentric phases during touchdown; it is quick and without movement. The concentric phase follows the amortization phase and comprises the entire push-off, until the athlete's foot leaves the surface (Baechle & Earle, 2008).

Maximum Oxygen Consumption

Maximum oxygen consumption refers to the highest rate at which the body can consume and utilize oxygen, and is well recognized as one of the main predictors of successful endurance performance for the broad population (Jones & Carter, 2000). Maximum oxygen consumption is limited by both the ability of the heart to pump blood to the working muscles and the ability of the working muscles to extract oxygen from the

delivered blood (Hoppeler & Weibel, 2000). Endurance athletes normally possess high maximum oxygen consumption values, and typically train to increase this variable. Improvements in maximum oxygen consumption are associated with increases in cardiac output and blood volume, which serve to increase the delivery of oxygen to the working muscles (Jones & Carter, 2000).

Many investigators have explored the effects of resistance training on maximum oxygen consumption. McCarthy, Agre, Graf, Poziniak, and Vailas, (1995) examined the effect of simultaneous strength and endurance training using a typical three-days-a-week strength routine. The strength training program consisted of four sets of five to seven repetitions for eight exercises, and the endurance protocol consisted of 50 minutes of cycle exercise at 70% of the heart rate reserve. A strength-only group, endurance-only group, and combined group trained for ten weeks. Subjects who performed the strength-only training or both types of training increased their one repetition maximum squat and bench press, vertical jump, and maximal isometric knee-extension strength as well as their fat-free mass. The endurance group demonstrated no changes in these variables, but did increase maximum oxygen consumption, as did the combined training group. The subjects used in this study were not trained collegiate distance runners. The results of this study showed that conventional training frequency and programs were in fact compatible and further indicated that overtraining may be the ultimate cause of incompatibility of concurrent strength and endurance training.

Hickson and colleagues (1980) showed that resistance training (five-days-a-week, ten weeks, five sets of five repetition maximum (RM); parallel squat, leg press, calf raise)

significantly improved endurance performance for both cycling (47%) and treadmill running (12%) in nine untrained subjects, despite no change in maximum oxygen consumption. The researchers suggested that the performances were related to increases in muscular strength and power. The finding of no change in maximum oxygen consumption following resistance training has been confirmed by Bishop, Jenkins, Mackinnon, McEniery, and Carey (1999); Paavolainen, Hakkinen, Hamalainen, Nummela, and Rusko (1999); Hoff, Gran, and Helgerud (2002). From the results of these studies, it appeared that when resistance training was performed in conjunction with endurance training in already well-trained individuals, maximum oxygen consumption did not improve beyond values that were achieved by endurance training alone because acute bouts of resistance training typically elicit oxygen consumption values of less than 50% of maximum oxygen consumption (MacDougall et al., 1979). Although resistance training will not improve maximum oxygen consumption, there is no evidence that resistance training will hinder an individual's maximum oxygen consumption or endurance performance.

Lactate Threshold

Lactate threshold refers to the point during exercise above which there is a one millimole per liter increase in blood lactate levels compared with baseline levels (Coyle et al., 1983), and represents the theoretical point during exercise whereby lactate production exceeds its removal (Brooks, 1985). Lactate threshold has been shown to be an important predictor of endurance performance over long-duration endurance events (Rhodes & McKenzie, 1990), because someone with a high lactate threshold has the

ability to run at a higher percentage of their maximum oxygen consumption without accumulating excess lactate.

Lactate threshold has been examined following resistance training in untrained and trained subjects. Marcinik et al. (1991) implemented a twelve - week resistance training program (three days a week, twelve week, three sets of ten repetition maximum; bench press, hip flexor, knee extension, knee flexion, push-up, leg press, lat-pulldown, arm curl, parallel squat, sit-up) in ten untrained male subjects with eight untrained men as controls. The training group demonstrated a 12% increase in their lactate threshold without a change in maximum oxygen consumption.

One of the most consistent findings of concurrent training studies has been that even heavy resistance training does not impair endurance performance. In fact, several studies indicated that strength training may actually increase markers of endurance ability (Hickson, 1980, 1988; Marcinik et al., 1991). For example, after twelve weeks of weight training three days per week, peak cycling oxygen consumption was unchanged, but cycling lactate threshold and time to exhaustion were elevated 12% and 33%, respectively (Marcinik et al., 1991). Unfortunately, all of the previously cited studies used untrained or moderately trained individuals as subjects. The effect that resistance training has on lactate threshold remains unclear, partially due to the limited amount of available literature.

Running Economy

Running economy is strongly related to distance running performance (Conley & Krahenbuhl, 1980; Morgan, Martin, & Krahenbuhl, 1989), and it is typically determined by measuring the steady-state oxygen consumption at submaximal running speed. Many endurance-sport events require high aerobic power, and maximum oxygen consumption is a good predictor of endurance performance in untrained subjects. However, some other factors, such as running economy (RE), may be better predictors of endurance performance than maximum oxygen consumption in a homogeneous group of well-trained endurance athletes (Billat & Koralsztein, 1996; Conley & Krahenbuhl, 1980; Morgan, Baldini, Martin, & Kohrt, 1989; Noakes, Myburgh, & Schall, 1990).

Taking body mass into consideration, runners with good running economy use less energy and therefore less oxygen than runners with poor running economy at the same speed. Researchers have reported a 20–30% range in the oxygen consumption for a given submaximal running speed among trained distance runners (Daniels, 1985; Kaneko et al., 1985; Morgan & Craib, 1992). Interindividual variability in running economy has been explained by various physiological, biomechanical, environmental, anthropometrical and psychological factors. Biomechanists have identified that running economy is affected by the net vertical impulse of the ground reaction force (Heise & Martin, 2001), stride length (Cavanagh & Williams, 1982), change in speed during ground contact phase (Kaneko et al., 1985) and vertical stiffness of a leg spring (Dalleau, Belli, Bourdin, & Lacour, 1998; Heise & Martin, 2001).

Combining strength and power with endurance training is difficult because of the conflicting demands of each type of activity and the possible antagonism of the training responses they elicit (Sale, 1988). The contrasting physiological demands of strength and endurance training may lead to interference, meaning that the training effect from one type of training negates the other (Hennessy & Watson, 1994; Zatsiorsky, 1995).

According to numerous studies, concurrent resistance training and endurance training had a profound impact on running economy. Millet, Jaouen, Borrani, and Candau (2002) found improvements in running economy (6.9%), one repetition maximum (1RM) half squat, and vertical jump height without concurrent changes in maximum oxygen consumption or body weight after 14 weeks of strength training using heavy weights among seven well-trained triathletes. The training in this study consisted of six different strength exercises for lower limbs, performed as three to five repetitions to failure in three sets, twice a week.

Paavolainen et al. (1999) reported improved 5-km running performance time (2.8%), improved running economy (7.8%), and improved sprint and jump performance among ten orienteering runners after nine weeks of sprints, jump, and strength training. The strength training in this study consisted of leg press and knee extensor-flexor exercises with low loads, but high movement velocities. No differences regarding maximum oxygen consumption or body weight were reported. The authors speculated that an improvement in neuromuscular characteristics, such as an increase in muscle stiffness and reduced time of the stretch-shortening cycle, caused these results.

Johnston, Quinn, Kertzer, and Vroman (1997) showed that a 29% increase in one repetition maximum squat improved running economy (3.8%) in six female distance runners after a ten week strength training program. This was a whole-body strength training program, performed as three sets of 6-20 repetitions, dependent on which type of exercise. Six repetitions per set were used for the parallel squat exercise. Following the resistance-training program, the athletes showed a 4% improvement in running economy and no significant changes in body weight or in maximum oxygen consumption were reported.

Spurrs, Murphy, and Watsford (2003) found approximately 6.5% better running economy (measured at three different set velocities) accompanied by a 2.7% improvement in 3-km running time after six weeks of plyometric training as a supplement to the regular running training among 17 moderately trained distance runners. Turner, Owings, and Schwane (2003) report 2.3% better running economy after six weeks of plyometric training as a supplement to regular running training among 18 moderately trained distance runners. These results are consistent in suggesting that resistance training may assist in increasing run performance by way of improving running economy.

Resistance training increases flexibility, which is beneficial for distance runners. Several studies contend that trunk and lower limb flexibility affect running economy (Cummings, Wall, Galbraith, & Belcastro, 1987; Gleim, Stachenfeld, & Nicholas, 1990; Godges, Macrae, & Longdon, 1989). Godges, Macrae, and Longdon (1989) observed that moderately trained athletic college students increased their running economy at all speeds

(40, 60, 80% of maximum oxygen consumption) with improved hip flexion and extension. Improved hip flexibility, myofascial balance, and pelvic symmetry are thought to enhance neuromuscular balance and contraction, eliciting a lower maximum oxygen consumption at submaximal workloads. These findings are compatible with the general belief among runners and coaches that improved flexibility is desirable for increasing running economy (Godges et al., 1989).

Age and Gender Related Differences for Resistance Training

Male and female distance runners have gender-related differences in physique, body composition, and physiological responses to resistance training. On average, adult women tend to have more body fat and less muscle and bone than adult males. Furthermore, women tend to be lighter in total body weight than men. Although some female athletes may have lower fat percentages than some male athletes, extremely low fat percentages in females may be associated with adverse health consequences (Otis, Drinkwater, & Johnson, 1997; West, 1998). Anthropometric measurements of adults indicate that men tend to have broader shoulders relative to their hips and women tend to have broader hips relative to their waists and shoulders. The broader shoulders in men can support more muscle tissue and can provide a mechanical advantage for muscles acting at the shoulder.

Even though both genders have a different physical make-up, both genders still benefit from resistance training. Whereas in the past some women may have questioned the value of resistance training or even avoided this type of exercise due to social stigmas, evidence clearly indicates that women are capable of tolerating and adapting to

the stresses of resistance exercise and that the benefits are substantial (Kraemer et al., 2001; National Strength and Conditioning Association, 1989).

In terms of absolute strength, women generally have about two-thirds of the strength of men (Lauback, 1976). The absolute lower body strength of women is generally closer to values of men as compared to the absolute values for upper body strength. Women who participate in a resistance training program can increase their strength at the same rate as men or faster. Although absolute gains in strength are often greater in men, relative (percentage) increases are about the same or greater in women. Judging by muscular development of female track and field athletes who have not used anabolic steroids, it is obvious that substantial muscle hypertrophy is possible in women who regularly participate in high-volume or high-intensity training programs (Baechle & Earle, 2008).

Although further study is warranted, it is possible that testosterone concentrations in women may vary with training and that woman with relatively high levels of testosterone may have more potential for an increase in muscle size and strength (Cumming et al., 1987; Hakkinen, 1994). Furthermore, it is possible that the complexity of the exercise movement used during training may influence the degree of muscle hypertrophy (Chilibeck, Calder, Sale, & Webber, 1998). More complex movements, such as the squat and bench press, as compared with the leg extension, may require a relatively longer neural adaptation period, thereby delaying muscle hypertrophy in the trunk and legs (Chilibeck et al., 1998).

Changes in Coaches, Coaching Philosophies, and Training Strategies

Prior to the 2010 track and field season there was no resistance training program for the distance runners. The resignation of the previous head track and field coach following the 2009 track and field season, and the appointment of a new track and field coach in advance of the 2010 track and field season, resulted in a change in coaching philosophy, which included the requirement of resistance training for distance runners. While the distance runners continued to be trained by the same event coach, all distance runners were also trained separately by a strength and conditioning coach.

All male and female student-athletes competing in middle and long distance events were required to participate in a resistance training program for the 2010 indoor and outdoor track and field season. This was a whole-body resistance training program that was performed two-days-a-week for sixteen weeks. Each exercise consisted of two-three sets of five-twenty repetitions with fifteen-thirty seconds of recovery between each set, while utilizing body weight, free weights, and machine weights. Each mesocycle was periodized throughout the season by changing the exercise selection, sets, repetitions, and recovery time. The exercises implemented into the program were selected based on their ability to strengthen the specific muscles, tendons, ligaments, and joints that are used in a running.

Phase 1-January 11-February 7			
Session 1		Session 2	
Walking Lunges	3x40m (30 sec. rest)	DB Step-Ups	3x15 (30 sec. rest)
DB Press	3x15 (30 sec. rest)	RDL	3x15 (30 sec. rest)
Hip-Ups	3x15 (30 sec. rest)	DB Shoulder Press	3x15 (30 sec. rest)
DB Bentover Row	3x15 (30 sec. rest)	Lat. Pulldowns	3x15 (30 sec. rest)
Back Extensions	3x15 (30 sec. rest)	Dorsiflex Machine	3x15 (30 sec. rest)
Phase 2-February 8-March 7			
Session 1		Session 2	
BB Jump Squats	3x8 (2 min. rest)	Explosive Step-Ups	3x8 ea. (2 min. rest)
Incline DB Press	3x12 (30 sec. rest)	Glute-Ham Raise	3x12 (30 sec. rest)
Inverted Rows	3x12 (30 sec. rest)	3-Way Sh Raise	3x12 (30 sec. rest)
Reverse Hyper	3x12 (30 sec. rest)	Resisted AB/Adduction	3x12 (30 sec. rest)
DB Runner Curls	3x30 sec. (30 sec. rest)	Calf Raises	3x12 (30 sec. rest)
Phase 3-March 8-April 4			
Session 1		Session 2	
DB Walking Lunge	3x40m (1 min. rest)	DB Step-Ups	3x20 (15 sec. rest)
SB Bench Press	3x20 (15 sec. rest)	Good Mornings	3x20 (15 sec. rest)
Single Leg Hip-Ups	3x10 ea. (15 sec. rest)	DB Shoulder Press	3x20 (15 sec. rest)
BB Bentover Row	3x20 (15 sec. rest)	Lat. Pulldowns	3x20 (15 sec. rest)
Back Extensions	3x20 (15 sec. rest)	Dorsiflex/Calf Raise Machine	3x20 (15 sec. rest)
Phase 4-April 5-May 2			
Session 1		Session 2	
BB Jump Squats	3x5 (2 min. rest)	Explosive Step-Ups	3x8 ea. (2 min. rest)
Incline DB Press	3x15 (15 sec. rest)	RDL	3x15 (15 sec. rest)
Reverse Hyper	3x15 (15 sec. rest)	SA DB Sh. Press	3x15 (15 sec. rest)
Prone DB Rows	3x15 (15 sec. rest)	DB Runner Curls	3x30 sec. (15 sec. rest)
3-Way Calf Raise	3x15 (15 sec. rest)	Dorsiflex Machine	2x15 (15 sec. rest)

Figure 1. Resistance training program for distance runners. DB = dumbbell; RDL = Romanian deadlift; BB = Barbell; Sh = shoulder; SA = single arm.

Purpose of the Study

There is extensive literature on the benefits of anaerobic training on aerobic performance characteristics. However, little research is available that seeks to show the benefits anaerobic training has on distance running performance. The main purpose of this study was to investigate the effect that simultaneous resistance training and endurance training had on distance running performance through the retrospective analysis of the existing public information of the entire collegiate indoor and outdoor track and field season by male and female distance runners who experienced the changes in coaches, coaching philosophies, and training strategies at the University of Wisconsin-Whitewater from 2009-2010.

The hypothesis is that simultaneous resistance training and endurance training resulted in improved distance running performances during the collegiate track and field season.

CHAPTER 2

METHODS

Fourteen male distance runners and eight female distance runners competed in the indoor track and field season in both 2009 and 2010 at the University of Wisconsin – Whitewater. Eleven male distance runners and six female distance runners competed in the outdoor track and field season in both 2009 and 2010 at the University of Wisconsin – Whitewater. These athletes experienced the changes in coaches, coaching philosophies and training strategies that occurred from 2009 to 2010, including the addition of resistance training during 2010.

Publicly available track and field meet results were obtained for all distance runners who competed in both 2009 and 2010 at the University of Wisconsin – Whitewater. The best performances in each event were identified for each athlete during the 2009 indoor track and field season, 2009 outdoor track and field season, 2010 indoor track and field season, and 2010 outdoor track and field season. These performances from different events were quantified to identify equivalent performance between different events using the Scoring Tables of Athletics published by the International Association of Athletics Federations (Spiriev & Spiriev, 2011a; Spiriev & Spiriev, 2011b).

The scores for 2009 indoor season and the scores for the 2010 indoor season were compared separately for men and women using Student's t-test for paired data and correlation analysis was performed to determine the regression equations and the strength

of the relationships. Similarly, the scores for 2009 outdoor season and the scores for the 2010 outdoor season were compared separately for men and women using Student's t-test for paired data and correlation analysis was performed to determine the regression equations and the strength of the relationships.

CHAPTER 3

RESULTS

Table 1 presents comparisons of the best performances of distance runners during the 2009 indoor track and field season with the best performances of the distance runners during the 2010 indoor track and field season for males and females. Males had a mean score of 817.92 ± 28.18 for the 2009 indoor season, while scoring 840.23 ± 22.63 for the 2010 indoor season. They have improved by 22.31 ± 5.55 . The males were near statistical significance with a p-Value of .0510. Females had a mean score of 679.75 ± 43.48 for the 2009 indoor season, while scoring 660.25 ± 44.83 for the 2010 indoor season. They declined by 19.50 ± 1.35 . The females reached statistical significance with a p-Value of .0462.

Table 1

Comparison of Best Performances from the 2009 Indoor Track and Field Season and the 2010 Indoor Track and Field Season

Gender	2009 Indoor Season	2010 Indoor Season	Difference	p-Value
Males (n=13)	817.92 ± 28.18	840.23 ± 22.63	22.31 ± 5.55	.0510
Female (n=8)	679.75 ± 43.48	660.25 ± 44.83	-19.50 ± 1.35	.0462

Note: n = number of subjects. Data are mean plus or minus standard error of the mean. p-Value was determined using a paired t-test.

Table 2 presents comparisons of the best performances of distance runners during the 2009 outdoor track and field season with the best performances of the distance runners during the 2010 outdoor track and field season for males and females. Males had a mean score of 764.45 ± 26.75 for the 2009 outdoor season, while scoring 834.45 ± 22.80 for the 2010 outdoor season. They have improved by 70 ± 3.95 . The males reached statistical significance with a p-Value of .0026. Females had a mean score 692.33 ± 49.25 for the 2009 outdoor season, while scoring 681.33 ± 64.99 for the 2010 outdoor season. They have improved by 11 ± 15.74 . The females were not statistically significant with a p-Value of .3382.

Table 2

Comparison of Best Performances from the 2009 Outdoor Track and Field Season and the 2010 Outdoor Track and Field Season

Gender	2009 Outdoor Season	2010 Outdoor Season	Difference	p-Value
Males (n=11)	764.45 ± 26.75	834.45 ± 22.80	70.00 ± 3.95	.0026
Female (n=6)	692.33 ± 49.25	681.33 ± 64.99	11.00 ± 15.74	.3382

Note: n = number of subjects. Data are mean plus or minus standard error of the mean. p-Value was determined using a paired t-test.

Figure 2 summarizes the comparisons of the best performances of distance runners from the 2009 and 2010 indoor track and field seasons and outdoor track and field seasons for males and females.

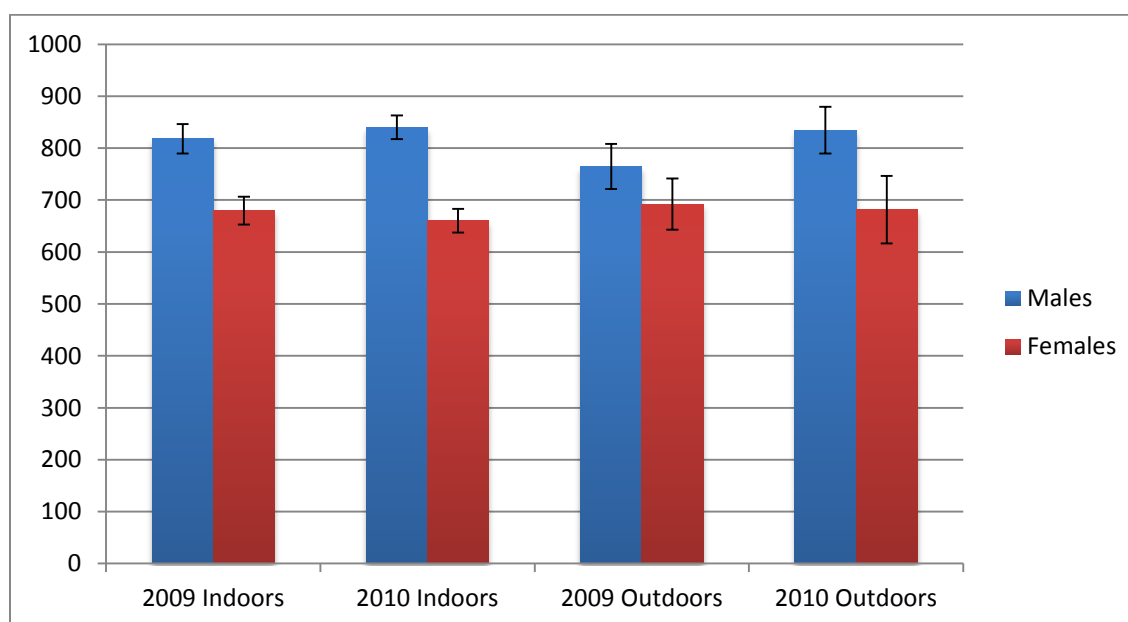


Figure 2. Comparison of the best performances of distance runners from the 2009 and 2010 indoor track and field seasons and outdoor track and field seasons for males and females. Note: Error bars represent standard error of the mean.

Figure 3 shows the correlation analysis comparing the best performance of males during the 2009 and 2010 indoor track and field seasons. The trend line demonstrates that males will increase in scoring from the 2009 to 2010. Males that score 899 and above will result in decreased future performance.

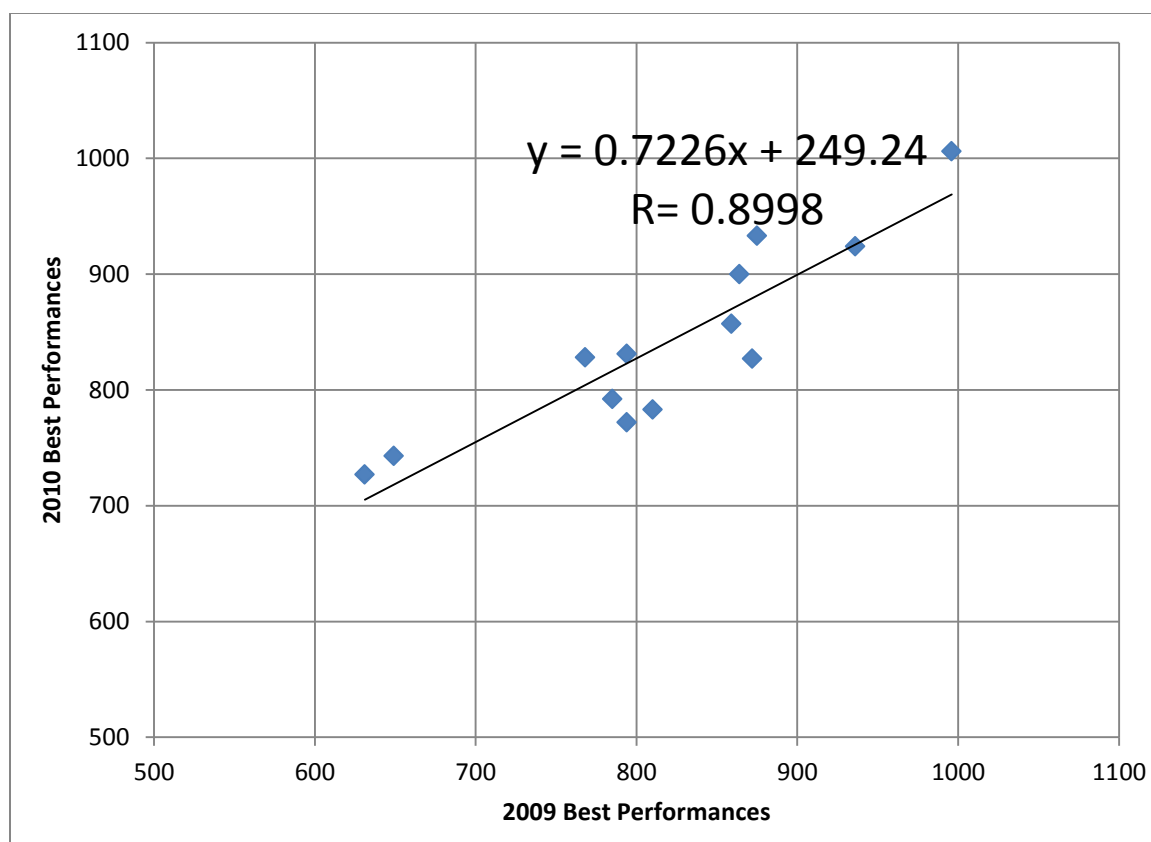


Figure 3. Correlation analysis comparing the best performance of males during the 2009 and 2010 indoor track and field seasons.

Figure 4 shows the correlation analysis comparing the best performance of males during the 2009 and 2010 outdoor track and field seasons. The trend line demonstrates that males will increase in scoring from the 2009 to 2010. Males that score 937 and above will result in decreased future performance

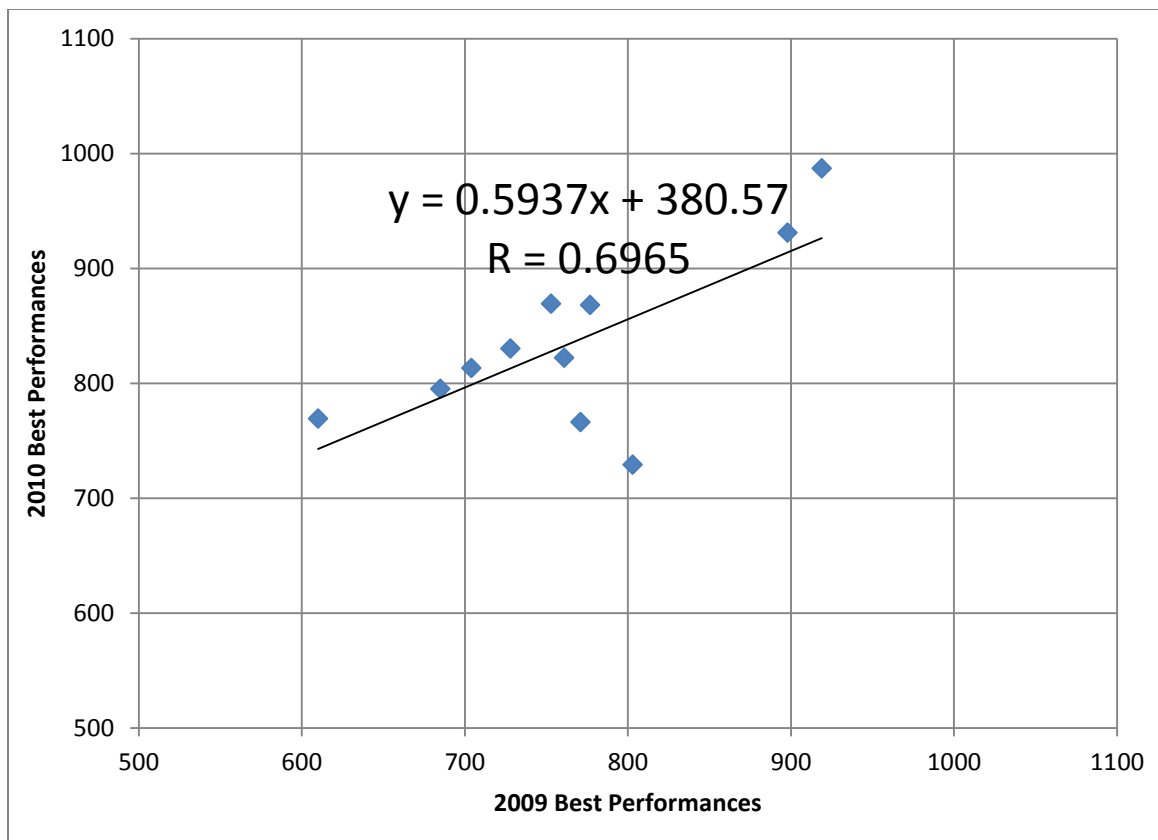


Figure 4. Correlation analysis comparing the best performance of males during the 2009 and 2010 outdoor track and field seasons.

Figure 5 shows the correlation analysis comparing the best performance of females during the 2009 and 2010 indoor track and field seasons. The trend line demonstrates that females who show a decrease in performance in 2009 will have a decrease in future performance.

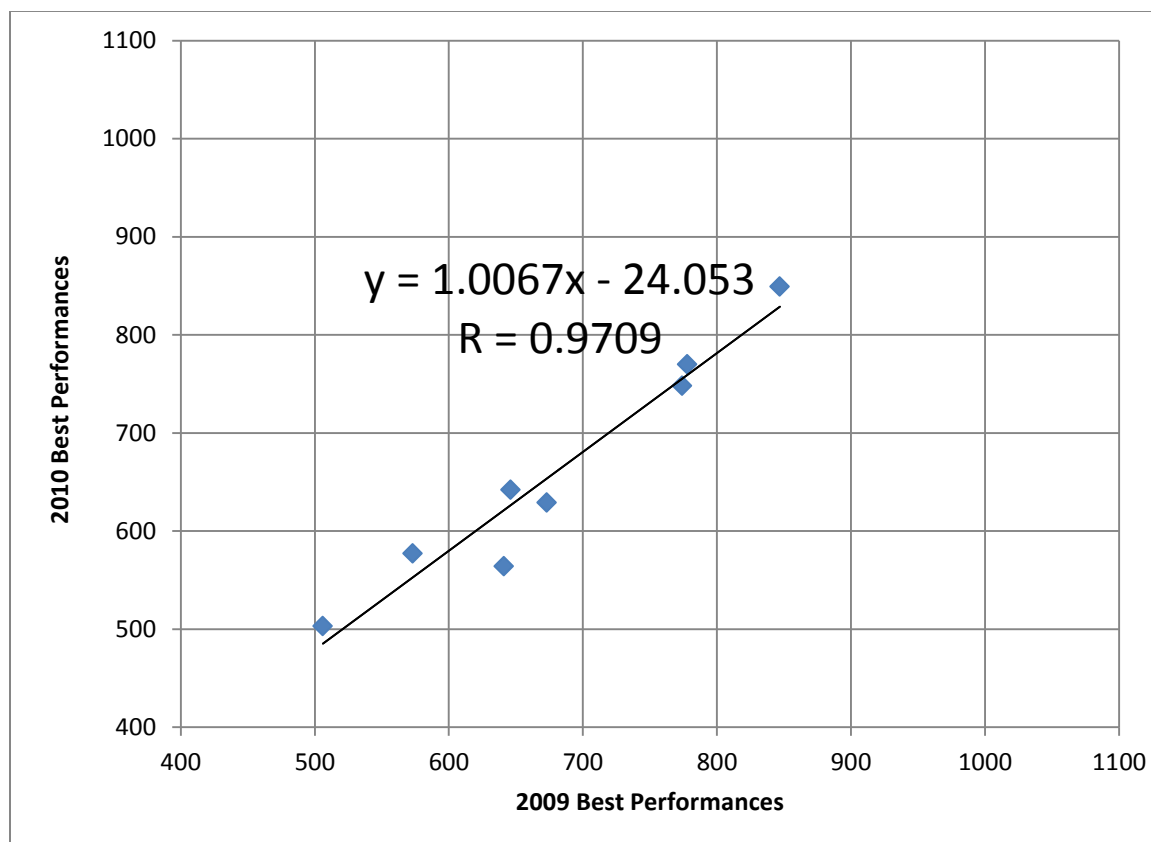


Figure 5. Correlation analysis comparing the best performance of females during the 2009 and 2010 indoor track and field seasons.

Figure 6 shows the correlation analysis comparing the best performance of females during the 2009 and 2010 outdoor track and field seasons. The trend line demonstrates that females who show a decrease in performance in 2009 will have a decrease in performance in 2010 except when the 2009 performance is higher. This is most likely due to the two females who showed improvements in 2009 and 2010. They were the highest scorers in 2009, which likely skewed the trend line. This created a result in which females who scored 732 or higher would increase in performance the next year as opposed to scoring lower. The best fit line could possibly be used to estimate what an individual could perform from one year to the next. The correlation coefficient shows how well the line fits the data. This demos how likely this equation would estimate the score from one year to the next.

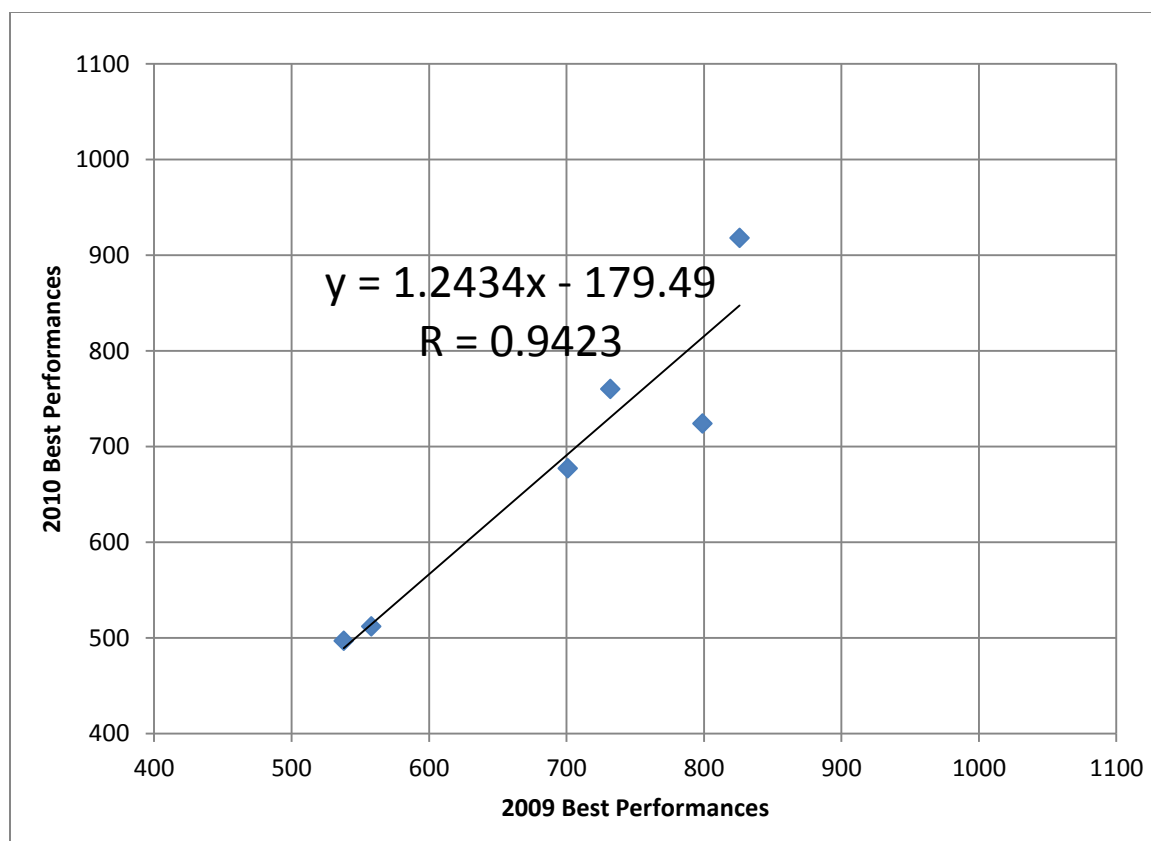


Figure 6. Correlation analysis comparing the best performance of females during the 2009 and 2010 outdoor track and field seasons.

Statistical significance was found between the women's indoor season and their distance performances ($P < 0.05$) and between men's outdoor season distance performances ($P < 0.05$). However, there was no statistical significance for the women's outdoor season and men's indoor season.

CHAPTER 4

DISCUSSION

The purpose of this study was to investigate the effect that simultaneous resistance training and endurance training had on distance running performance throughout an entire collegiate indoor and outdoor track and field season. Although it is known that training for strength and endurance are not compatible when strength increases are the goal, much less is known about the role of simultaneously training for strength and endurance on endurance-related performance.

The males had increased performances from both seasons from 2009-2010. The females had decreased performances from both seasons from 2009-2010. Statistical significance was found between the women's indoor season and their distance performances ($P < 0.05$) and between the men's outdoor season distance performances ($P < 0.05$). However, there was no statistical significance for the women's outdoor season and men's indoor season.

The explanation behind these findings for the women could be that they became overtrained as the season progressed. The female body is different from that of a males and this could have played a role in the decreased performances over an extended period of competition. Evidence indicates that women are capable of tolerating and adapting to the stresses of resistance exercise and that the benefits are substantial (Kraemer et al., 2001; National Strength and Conditioning Association [NSCA], 1989), but in this case it

seems that women are incapable of tolerating and adapting to the simultaneous stresses of resistance training and anaerobic training.

The explanation behind the men's finding could be that men have an adverse initial reaction to resistance training, but the body is more willing to tolerate and adapt to the double stressors of resistance training and aerobic training throughout the collegiate track and field season.

Improved distance running performance was evident in this study, although it was not accompanied by all of the genders and seasons. Possibly these improved running performances were due to an increase in running economy or the strengthening of the skeletal musculature, bones, ligaments, and tendons through the resistance training that was implemented during the competitive season.

Distance runners experience three competitive seasons per year in their collegiate season. These include the cross country, indoor, and outdoor track and field season. Runners will experience a significant amount of training stress on their bodies throughout a calendar year. A majority of the runner's in this study did not participate in an organized resistance training routine prior to this study, which explains the amount of injuries that were incurred during the previous seasons. Season best and personal bests can only be performed when the athlete is 100% healthy especially at the collegiate level. This added variable in their training could have positively affected their running performances. Distance runners should view resistance training as a measure to prevent injuries throughout the year.

Not all subjects experienced improved running performance from one season to the next with the implemented resistance training program. Some individuals experienced significant downfalls in their respective events. This is due to many factors such as poor nutrition, binge drinking, lack of sleep, time spent on feet (walking in between classes), social stress, academic stress, sickness, and injury. One argument could be made about the added physical stress of the resistance training program. This program was implemented during the first week of indoor season competition with no prior strength training up to that point. The individual's body could have reacted negatively to the running training, racing, and resistance training (triple stressor), their body might have been overloaded, and as a result, that person was injured and overtrained.

There was an emphasis on strengthening the muscles that were involved with the running gait cycle. The two phases of the gait cycle are the stance phase and the swing phase. The quadriceps group is heavily active before initial contact in the stance phase. Once contact is made, the muscles, tendons, bones, and joints of the foot and lower leg function to absorb the impact of the landing. After initial contact are made during the swing phase, the hamstrings and hip flexors, the quadriceps, and the muscles of the calf work in conjunction to allow a proper takeoff. The arms also function to stabilize and balance the body during running. Poor arm carriage could hinder running efficiency and running economy.

A high volume of reps were used with minimal rest to increase muscular endurance and to decrease the amount of time in the weight room due to the decrease in testosterone levels after 50 minutes and the lack of time a student-athlete has to train

during the school year. A typical day of practice for an athlete includes their running workouts, strength workouts, and recovery, i.e. stretch, foam roll, and ice bath. This combined with their academic studies can be overwhelming, it is wise on the coaches half to make workouts quick and effective.

The volume and exercises would vary throughout the indoor and outdoor seasons to accommodate the aerobic training performed beforehand. The aerobic training is strategically periodized so that the athlete can peak during the conference and national championships. The competition phase usually are based on a high amount of volume and low intensity type aerobic training with less rest time between sets and the championship phase is based on a low amount of volume and high intensity type aerobic training with more rest time between sets.

All the exercises were chosen for a specific reason, with an emphasis on lower body strength due to the amount work done by the lower body throughout running. Exercise variations were used to prevent adaptation and boredom with the resistance training program.

The dumbbell bench press strengthens the pectoral groups and abdominals, which improves the posture of a distance runner. The better posture provides for a more efficient gait cycle, which helps during the latter stages of a distance race. The dumbbell shoulder press and three-way shoulder raise strengthens the shoulder muscles and core, which results into improved posture and the arm carriage. The latissimus dorsi pulldown, back extension, and rowing exercises strengthen the back, which help counterbalance

strength gained from abdominal and pressing exercises. A balanced torso helps maintain an erect posture and aid in developing a powerful arm carriage throughout a race.

The lunge exercise primarily strengthens the quadriceps and hamstring muscle groups, while strengthening the core. This exercise helps strengthen the main muscles used in running, which improves running form throughout a race. The explosive step-up and jump squats are similar to the lunge as far as muscles used during the exercise, but the main difference is the explosive characteristic to the exercise, which stimulates the central nervous system and improves speed. This exercise was incorporated when speed was an emphasis during that training cycle. Good morning and Romanian deadlift emphasizes the hamstring, gluteus maximus, and lower back. These exercises not only strengthen the aforementioned muscles, but it also stretches these muscles.

The hip adduction exercise was used to strengthen adductor muscles of the thigh. This exercise aids in the powerful extension in the propulsion phase of running and prevents imbalances in the quadriceps. The abduction exercise was used to strengthen the abductors of the thigh, especially the gluteus maximus. This exercise aids in preventing piriformis pain, which is often experienced by distance runners.

The calf muscle and Achilles tendon take on much of the shock absorption and deflection after heel strike when running during a distance race. Calf raises alleviate this problem through strengthening calf and Achilles tendon. Dorsi flexion raises were used to strengthen the tibialis anterior to counterbalance the calf raises and increase strength and flexibility in the ankle.

Limitations

While this study represented a wide range of distance running events in track and field, the total group contained a small amount of participants, which limits the conclusions that may be drawn. The data should not be ignored, however, as these may be important indicators in performance and could lead to further, more in-depth studies in the future.

Additionally, no data was obtained from freshman distance runners because we could not compare their two seasons because they were in their first year of competing in collegiate track and field distance events. High school track and field participates in the 800, 1600, and 3200 meter runs, while collegiate track and field participates in the 800, 1500, 1600, 3K, 5K, 10K, and 3K steeplechase.

This study looked at NCAA Division III distance athletes, studies of high level athletes, such as Division I athletes or post-collegiate athletes, may result to other findings.

Future Suggestions

It is recommended that further studies should be conducted on simultaneous resistance training and distance running performance. There is a need for investigating a greater amount of subjects at a higher level of ability to help improve the strength of the study. A single year of simultaneous training only gives a limited amount of results, especially when the simultaneous training was only performed during the competition season. Testing throughout one's entire collegiate running career would improve the validity of the study and may need to be addressed for future research.

Practical Applications

Even though the data from this study isn't overwhelming, it does suggest that adding a resistance training program to a distance training program can improve a male athletes overall running performance, while adding a resistance training program to a distance training program for female athletes would result in decreased performance. I am not suggesting that just lifting weights will make a male distance runner better or adding a resistance training program will make them become an elite distance runner. I'm suggesting that through proper resistance training, the anatomy will be strengthened, and this will result in aided running performance by eliminating muscular imbalances that impede the gait cycle and help eliminate injuries that result from muscle imbalances for male distance runners.

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