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Performance Effects of a Strength Training Program in Collegiate Runners

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Performance Effects of a Strength Training Program in Collegiate Runners

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ABSTRACT

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Research has shown that lower limb asymmetries can negatively impact performance and risk of injury. However, there is little research on the effects of lower limb asymmetry on running performance, nor the effects of strength training on lower limb asymmetry in runners. The purpose of this study was to examine the relationship between jumping ability and asymmetry and long distance running performance, as well as to determine the performance effects a strength training program has on collegiate runners. Data from athlete monitoring of 10 collegiate distance runners and 6 sprinters were analyzed. Athletes (Distance Runners n = 10, Sprinters n = 6) performed static and countermovement jumps at two testing sessions separated by 21 weeks, during which, they participated in a block-periodized strength training program. The athletes were capable of maintaining a minimal amount of kinetic asymmetry during the jump tests and there were no statistically significant correlations between jump height, jump asymmetry, and cross-country race times. After the strength training intervention, the female distance runners significantly improved static jump height (p value = 0.045), countermovement jump height (p value = 0.015), countermovement jump asymmetry percentage (p value = 0.006), and body fat percentage (p value = 0.002). Although there were no other statistically significant changes, there were promising trends in many of the performance variables. These results indicate that there are potential benefits associated with strength training, and coaches should incorporate it into the overall programming for collegiate runners for injury prevention and enhanced performance.

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Chapter 1. Introduction

Lower limb asymmetry has been shown to impact the incidence of injuries and affect athletic performance (Croisier et al., 2002). Bishop et al. (2018) suggested that countermovement jump asymmetries of >5% can be associated with reduced jumping, sprinting and change of direction performance. Research has shown a strong inverse relationship between isometric strength and lower limb asymmetry, indicating that weaker athletes had greater asymmetry and that a strength training intervention can improve lower limb asymmetry during an isometric squat (Bazyler et al., 2014).

There is little research, however, on the effects of lower limb asymmetry on running performance. Further, most of the research done has been an examination of the effects on sprint performance, not long-distance performance (Exell et al., 2015). Because running economy, an important determinant of long distance running performance, may be negatively influenced by lower limb asymmetries, it would be of importance to examine the relationship between lower limb asymmetry and long distance running performance, as well as whether strength training helps to improve asymmetry in runners (Beck et al. 2018; Zifchock et al., 2008).

Hudgins et al. found strong, positive correlations between jumping ability and running performances in the 60, 100, 200, 800, 3,000, and 5,00 meter race times (Hudgins et al., 2013). Because of the strong relationships between performance and jumping ability, jump tests should be useful in investigating the effects of asymmetry on a variety of performances.

The aim of our study was to examine the effects a strength training program has on collegiate runners. This study was a further analysis of jump parameters from athlete monitoring data performed by Milligan University's cross-country and track and field teams. We researched jump characteristics including jump height and jump asymmetry percentage. We examined the relationship between these characteristics and average cross-country race time for each athlete. Additionally, we analyzed the effect that a 21-week strength training intervention had on the jump characteristics in the distance runners as well as sprinters.

This dissertation is important to the field of sport science for athlete monitoring, injury prevention, and performance enhancement. Coaches can assess jump height and jump asymmetry more rapidly than measuring running asymmetry. This could help coaches to easily assess athletes and determine if adjustments should be made to their training and/or mechanics in order to reduce the risk of injury and potentially optimize running performance. This information can provide a better understanding of the effects of lower limb asymmetry on distance running performance since there is a gap in the literature. Additionally, valuable information would come from knowing if strength training could help to reduce jump asymmetry, potentially enhancing running performance. This research could offer more convincing evidence for distance coaches to incorporate a strength training program into their athletes' regimen, as strength training is still an uncommon modality in the distance community.

Chapter 2. Literature Review

Running is a dynamic combination of joints and muscles working together to produce fluid locomotion. The running gait cycle consists of a series of movements of the lower extremities between the initial foot impact on a surface until that foot reconnects with the surface again at the end of the cycle (Nicola & Jewison, 2012). Chan and Rudins (1994) classify locomotion based upon speed; walking is defined as 01.32 m x s^{-1}, jogging is 3.31 m x s^{-1}, running is 4.77 m x s^{-1}, and sprinting is 10.8 m x s^{-1} (Chan & Rudins, 1994).

Competitive collegiate running consists of two separate sports; cross country and track and field. Cross country is a fall sport, while track and field is a spring sport. During cross country, women compete in a 5,000 meter race and men compete in an 8,000 meter race. In the sport of track and field, runners are typically divided into two main categories: sprinters and distance runners. These categories are defined by the events in which the athletes compete. Sprinting events are ≤ 400 meters, while middle distance and distance events are ≥ 800 meters.

Due to the specific demands of the events, sprinters and distance runners differ in their physiology, body composition, and biomechanics. Competing in short distances, the main focus for sprinters is maximizing horizontal velocity over as short of a time as possible. A sprinter's performance is related to their ability to accelerate, maximal velocity and peak velocity maintenance (Petrakos et al., 2016). Sprinters characteristically have more muscle mass than distance runners partly due to the increased Type II muscle fiber content needed for maximal force output (Hammer et al., 2010). In contrast, distance runners typically have less total body mass and muscle mass than sprinters, exhibiting more Type I muscle fiber content. Due to the length of distance races, primary performance indicators for these runners are $\dot{V}O_2$max, running economy, lactate threshold, and critical velocity (Conley & Krahenbuhl, 1980; Hill, 1993).

Running Economy

Success in distance running has long been attributed primarily to an athlete's ability to consume oxygen maximally ($\dot{V}O_2$max). Although a high $\dot{V}O_2$max may be a prerequisite to be an elite distance runner, there are additional qualities that are needed to be successful, such as running economy (Conley & Krahenbuhl, 1980). Running economy, defined as the metabolic cost to cover a given distance at a constant velocity, is typically expressed as the volume of oxygen consumption per unit of body mass required to run a kilometer (Beattie et al., 2017). Running economy has been shown to be a stronger indicator of endurance performance than $\dot{V}O_2$max alone within elite homogenous populations (Beattie et al., 2017). Conley and Krahenbuhl et al. (1980), very well-trained distance runners, found that 65.4% of the variation in a 10 kilometer race performance could be explained by variations in running economy.

Research has shown that the neuromuscular adaptations resulting from strength training help to improve performance in distance runners by improving running economy (Beattie et al., 2017; Johnston et al., 1997; Storen et al., 2008). It was suggested that these improvements are related to increases in leg strength and alterations in motor unit recruitment patterns (Johnston et al., 1997). Additionally, Stone et al. (2006) suggest that stronger athletes have more efficient movements, leading to enhanced endurance capabilities as a result of performing less work.

Asymmetry & Injuries

Approximately one half of all recreational runners will sustain an injury in a given year (Walter et al., 1989). Many of these running injuries are recurring and on the same side of the body. This unilateral development of an injury suggests that one side of the body does not mirror the other during the running gait cycle.

A possible injury risk factor for runners is lower limb asymmetry, which previously has been shown to impact the incidence of injuries and affect athletic performance (Croisier et al., 2002). Running is a bilateral cyclic activity that can impose high forces and stress on the body, particularly lower body joints, through highly repetitive movements. Runners, especially track athletes, may assume misaligned positions of the trunk and lower limbs in order to control these forces, thus causing an asymmetry; a difference between limbs regarding either kinematic or kinetic parameters (Zifchock et al., 2008). Lower limb asymmetry suggests that one limb is exposed to more stress than the other, causing it to be more prone to injury. Unfortunately, an injury threshold level discriminating normal from problematic gait asymmetry does not exist and there are wide variations of gait asymmetries among athletes (Gilgen-Ammann et al., 2017). Possible mechanisms of asymmetry related injuries may be due to imbalances in strength, structure, or gait, or a combination of these factors (Zifchock et al., 2008). Knowledge of an athlete's asymmetry while running is important for coaches in order to determine if adjustments should be made to their training and/or mechanics in order to reduce the risk of injury.

Asymmetry & Muscular Strength

Lower limb muscular strength plays a key role in stabilizing the body in order to better absorb impactful forces and produce peak forces that will propel the body forward while running. As previously stated, strength asymmetry could be a possible mechanism related to injury in runners.

Knapik and et al. (1991) investigated 38 female collegiate athletes through the duration of their seasons. The results showed that when athletes had specific strength imbalances of 15% (unilateral isokinetic torque) or more during pre-season testing, they were 2.6 times more likely to sustain an injury than those who were more symmetric (Knapik et al., 1991). Similarly, in their review, Niemuth et al. (2005), found that injured runners were weaker on their injured sides, suggesting that the strength imbalance may have increased the risk of injury for the weaker side (Niemuth et al., 2005). However, most of these early studies used open kinetic chain measurements that reflect a relatively low degree of running task specificity (Graham et al., 1993; Svoboda et al., 2016).

Researchers have begun to examine effects of closed kinetic chain strength level and strength training using multi-joint closed kinetic chain programs on asymmetry. Bazyler et al. (2014) hypothesized that if symmetrical force production is desired, then strength training may reduce strength asymmetry (Bazyler et al., 2014). Their findings showed a strong inverse relationship between squat isometric strength and lower limb asymmetry, indicating that weaker athletes had more asymmetry. Additionally, the weaker athletes who participated in the 7-week bilateral strength training intervention (squats) were able to decrease their asymmetry. The athletes who were categorized as “strong” however, showed little improvement in their already low asymmetry levels (Bazyler et al., 2014).

Asymmetry & Running Economy

Running economy may be negatively influenced by biomechanical asymmetries (Beck et al., 2018). In one study, researchers examined the differences between ground reaction forces and metabolic rates during running trials in which the same individuals ran with symmetric and then asymmetric step times. For every 10% increase in step time asymmetry, net metabolic power (VO_2) increased by 3.5% (Beck et al., 2018). The researchers concluded that running with asymmetric step times increases the rate of metabolic energy expenditure, negatively affecting running economy, and that runners likely can use symmetric biomechanics to enhance distance-running performance.

Asymmetry & Performance

Although research has consistently shown that lower limb asymmetries may lead to an increased risk of injury, there is limited literature regarding the effects of lower limb asymmetry on running performance. Exell et al. (2015) investigated the interaction between asymmetry in sprint performance and lower limb strength. By collecting vertical ground reaction force data, from jump squats, the authors found that bilateral strength imbalances did not entirely account for asymmetry in performance variables during sprint running (Exell et al., 2015). Additionally, Haugen (2018) examined the association between stride cycle asymmetry and sprint performance. No significant changes were observed in asymmetry between the runners' best and worst trials, concluding that kinematic asymmetries were not associated with maximal sprint running performance (Haugen et al., 2018).

However, Madruga-Parera et al. found that jump-based asymmetries were negatively associated with jump height, change of direction, and repeated sprint performance in youth handball athletes (Madruga-Parera et al., 2020). Additionally, Hudgins et al. (2013) found strong, positive correlations between jumping ability and running performances in the 60, 100, 200, 800, 3,000, and 5,000 meter races. Therefore, jump asymmetry and jump ability may be related to running performance.

Most researchers have only analyzed the interaction between lower limb asymmetry and performance during sprinting events. Sprinters are typically stronger than distance runners and therefore may have less asymmetry to begin with (Bazyler et al., 2014; Novacheck 1998) Because of these physiological and performance differences and event-specific demands, it would be of interest to examine the baseline differences in lower limb asymmetry between sprinters and distance runners. With sprinting events being ≤ 400 meters and most lasting only seconds, it would be of interest to also analyze the interaction between lower limb asymmetry and running performance during longer distance events, such as 5,000 and 8,000 meters.

Current evidence indicates that lower limb asymmetry is a risk factor for injuries in runners and that a possible mechanism may be due to imbalances in strength; causing one side of the body to undergo more stress and/or produce force than the other (Zifchock et al., 2008). Participating in a strength training program has been shown to reduce asymmetrical force production during a squat (Bazyler et al., 2014) and improve performance in distance runners by improving running economy (Beattie et al., 2017; Johnston et al., 1997; Storen et al., 2008). Although some research suggests that lower limb asymmetries do not affect performances during sprinting events, little is known on the outcomes for longer distance events (Exell et al., 2015; Haugen et al., 2018).

It would be valuable for coaches and researchers to determine the interaction between lower limb jump asymmetry, jumping ability and long-distance running performance. Jump asymmetry and performance can be more rapidly measured and requires less equipment than measuring running asymmetry. It would also be of interest to examine whether a strength training program improves jumping ability and symmetrical force producing capabilities of runners. This information could be used to adjust training programs that will optimize a runner's performance as well as reduce the risk of injury.

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Chapter 3.

THE RELATIONSHIP BETWEEN JUMP PARAMETERS AND RUNNING PERFORMANCE OF A COLLEGIATE CROSS-COUNTRY TEAM

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The relationship between jump parameters and running performance of a collegiate cross-country team

Abstract

Lower limb asymmetries can have negative effects on not only injury risk, but also on performance. Due to the strong relationships between jumping ability and performance, jump tests should be useful in investigating the effects of asymmetry on a variety of performances. The purpose of this study is to determine the relationship between jump height, jump asymmetry, and cross-country race performance in collegiate distance runners. Fourteen athletes (7 males, 7 females) on an NAIA cross-country team were part of an athlete monitoring program. Correlation matrices were created to examine the relationships between their jump parameters and average race time. The average demographics for all athletes was 20.1 ± 1.2 years old, 170.9 ± 7.7 cm tall, and they weighed 59.7 ± 7.2 kg. The average static jump asymmetry percentage for all athletes was 4.5 ± 2.2 % and the average countermovement jump asymmetry was 7.9 ± 6.1%. The results showed that these athletes had low asymmetries and there were no statistically significant relationships between jump asymmetry and race time.

Introduction

Athlete performance and the importance of asymmetry has been debated in the literature with no clear resolution (Maloney et al., 2019). One important factor is the type of test used; vertical jumps, particularly countermovement jumps (CMJ), have been commonly used to assess performance. Jump ability has been shown to have strong relationships with other sport related variables such as change of direction, sprint, and endurance performance. For example: Hudgins et al. (2013) found strong, positive correlations between jumping ability and running performances in the 60, 100, 200, 800, 3,000, and 5,000 meter races. Because of the strong relationships between performance and jumping ability, jump tests should be useful in investigating the effects of asymmetry on a variety of performances.

Interestingly, the results of several studies have linked jump asymmetries to an imbalance of muscle development and strength, motor control issues (Bell et al., 2014; Baily et al. 2015), suboptimal performances (Bailey C. et al., 2015; Bell et al., 2014; Bishop et al. 2019, Owens, et al., 2011; Madruga-Parera et al., 2020), and a greater potential risk for injury (De la Motte et al., 2017; Knapik et al., 1991).

Conversely, other studies have not found statistically significant evidence that asymmetry, particularly as measured by jumping, affects poor performance. For example: jumping/hopping asymmetries did not appear to affect sprinting, change of direction or soccer performance (Hoffman et al., 2007; Lockie et al., 2014; Pardos-Mainer et al., 2021). Indeed, there is evidence that asymmetry in most athletes is likely associated with the task specificity of their sport (Gstöttner et al., 2009; Hart et al., 2017; Read et al., 2018; Sannicandro et al., 2011). Many of these asymmetries are likely to be at least partially a function of limb dominance and are probably magnified by long-standing participation within a specific sport. It is quite plausible that some degree of asymmetry may be an adaptation which might result in a superior performance, such as track athletes running around the track in the same direction.

As most athletes (and sedentary subjects) show some degree of asymmetry, the possibility of a threshold asymmetry value indicating suboptimal performance, and perhaps increased injury potential, has been examined by several researchers. For example: Bishop et al. (2018) suggested that countermovement jump asymmetries of >5% can be associated with reduced jumping, sprinting and change of direction performance. Jump asymmetries of approximately 10% have been related to reduced jump heights (Bell et al., 2014); and jump asymmetries of >12% were associated with reduced acceleration abilities (Bishop et al., 2021).

Considering the relationship of jumping asymmetries and sport related performance such as acceleration, and change of direction, it is quite possible that jump related asymmetry could be related to sustained performance such as performance during distance running. In addition to a high $\dot{V}O_2max$, endurance runners must be efficient and economical in order to be successful at the elite level (Beattie et al., 2017). Indeed, as running economy is related to mechanical efficiency, an investigation of the effects on running economy and asymmetry would be useful. However, there is little research analyzing the interaction between lower limb asymmetry and distance running performance.

Running economy may be negatively influenced by lower limb asymmetries (Beck et al. 2018; Zifchock et al., 2008). However, as asymmetries can be the result of injury or sport specific practices, such as running the same direction on a track, it is unclear as to how asymmetries might affect running on a straight surface (non-curve running). Therefore, it should be useful to assess runners for lower limb asymmetries. The purpose of this study is to determine the relationship between jump height, jump asymmetry, and cross-country race performance in collegiate distance runners.

The importance of this study to sport science is in providing valuable information on how jump height and jump asymmetry may be related to running performance. Jump height and jump asymmetry can be more rapidly measured and requires less equipment than measuring running asymmetry. This could help coaches to easily assess athletes and determine if adjustments should be made to their training and/or mechanics in order to optimize running performance.

Methods

Athletes

The athletes were 14 trained male and female collegiate distance runners (18-22 years) from an NAIA University Cross-Country team. All athletes were part of East Tennessee State University's Sports Science athlete monitoring program. To be included, athletes met the following inclusion criteria: free of cardiovascular or musculoskeletal injury or illness, completed all tasks of the testing session, competed in all races of the team's 2019 Cross-Country season. All athletes previously consented to allow their monitoring data to be included in the ETSU Sport Science repository system and to be used in this study. The study was approved by the University IRB (c1120.9sd).

Procedures

Upon arrival at the sport science lab, each athlete provided a urine sample to ensure adequate hydration status before participating in the series of tests. Their age, height, and body mass were then recorded. Lange skinfold calipers (Beta Technology Inc., Cambridge, MA, USA) were used to measure skinfolds at each of the 7 sites (triceps, subscapular, chest, midaxillary, suprailiac, abdomen, and thigh) following ACSM guidelines (ACSM, 2010) in order to calculate body fat percentage. The Jackson & Pollock 7-site skinfold equations for men and women were used to calculate body density and then body fat percentage (Jackson, Pollock, and Ward, 1978; Jackson, Pollock, and Ward, 1980).

Athletes proceeded to complete a standardized warm-up of 25 jumping jacks, 5 mid-thigh clean pulls at 20kg, and then 3x5 mid-thigh pulls at 40kg for females and 60kg for males. They then performed two types of jumps: a static jump (SJ) and a countermovement jump (CMJ), while holding a near-weightless PVC pipe on their shoulders. All jump tests were performed on a platform with dual force plates (Rice Lake Weighing Systems, Rice Lake, WI). For the SJ, athletes descended into a squat position until they reached a 90° knee angle. Once stable, the tester shouted "3, 2, 1…jump" and the athlete jumped straight up. Athletes performed two warm-up jumps at 50% and 75% of perceived maximal effort before performing at least 2 maximal jumps. Athletes completed more than 2 maximal jumps if the difference between the two previous jumps was ≥ 2 centimeters. Following SJ, athletes performed CMJ. For CMJ, athletes stood upright on the platform until the tester shouted "3, 2, 1…jump", then performed a countermovement by dropping down to their preferred depth and then jumping straight up. Similar to SJ, athletes performed one 50% and one 75% warm-up jump before completing at least 2 maximal CMJ. If the difference between the two jumps was ≥ 2 centimeters, the athlete performed additional jumps. Jump data was analyzed using LabView 2010 software (National Instruments, Austin, TX) and Microsoft Excel (Microsoft Corporation, Redmond, WA, version 16.25). The 2 highest SJ and CMJ were used to calculate jump height and asymmetry percentage for each. Asymmetry percentages were calculated as a percent, using net impulse from the left and right side as follows: (Highest-Lowest) / (Highest + Lowest)*100.

An average race time for the 2019 cross-country season was calculated for each athlete. Results for the women's 5,000 meter and men's 8,000 meter races were collected from the official website of the NAIA. The athletes competed in 5 races during the season, including the NAIA National Cross-Country Championships.

Statistical Analysis

Data from the athlete's demographics and performance parameters were analyzed using Microsoft Excel (Microsoft Corporation, Redmond, WA, version 16.25) by calculating averages and standard deviations. A Shapiro-Wilks normality test was used to determine if the data were normally distributed using R (version 4.0.4). Correlation matrices of the average values to establish relationships between variables were also created. For all tests, the alpha level was set at $p \leq 0.05$.

Results

Physical Characteristics

Athlete demographics are shown in **Table 3.1**. The athletes consisted of 7 males and 7 females. All were trained cross-country runners, ranging from 18 to 22 years old. For all athletes, the average SJ0 height was 25.9 ± 4.6 cm and the average CMJ0 was 27.8 ± 4.8 cm. The average body fat percentage for all athletes was 10.0 ± 5.7%. On average, the males (20.4 ± 1.1 years) were older than the females (19.7 ± 1.2 years). Additionally, the males were taller (176.4 ± 5.0 cm) and had a greater body mass (65.04 ± 5.33 kg) than the females (165.4 ± 5.6 cm; 54.5 ± 4.3 kg). However, the females had a higher body fat percentage (14.6 ± 4.7%) than the males (5.5 ± 1.1%).

Performance Parameters

The athletes' performance parameters are shown in **Table 3.2**. On average, the males had a higher SJ0 height (29.0 ± 3.3 cm) and CMJ0 height (30.8 ± 3.5 cm) than the females (22.9 ± 3.5 cm; 24.7 ± 3.9 cm). The males also had a higher SJ0 asymmetry percentage (4.9 ± 2.2%) than the females (3.8 ± 2.1%). However, the females had a higher CMJ0 asymmetry percentage (8.0 ± 8.2%) than the males (7.9 ± 3.7%). The average 5,000 meter race-time for the females was 19:13.00 ± 45.02 and the average 8,000 meter race-time for the males was 26:09.00 ± 34.85.

Table 3.3 displays the results of a Pearson correlation performed on all variables from athletes. The highest correlation was between SJ0 and CMJ0 with an *r* value of 0.934, indicating a strong positive correlation. Other notable relationships were between height and weight (*r* =

0.841), between body fat percentage and SJ0 (r = -0.602), and between body fat percentage and CMJ0 (r = -0.605).

Table 3.4 displays the results of a Pearson correlation performed on all variables from female athletes only. Again, the highest correlation was between SJ0 and CMJ0 with an r value of 0.928, indicating a strong positive relationship. Other notable relationships were between weight and body fat percentage (r = 0.782) and between weight and SJ0 asymmetry percentage (r = 0.782).

Table 3.5 displays the results of a Pearson correlation performed on all variables from male athletes only. The highest correlation was between age and height with an r value of 0.861, indicating a strong positive relationship. Other notable relationships were between height and CMJ0 asymmetry percentage (r = 0.856) and between weight and CMJ0 asymmetry percentage (r = 0.785).

Table 3.1. Athlete Demographics

	All (n=14)	Females (n=7)	Males (n=7)
Age (years)	20.07 ± 1.16	19.71 ± 1.16	20.43 ± 1.05
Height (cm)	170.93 ± 7.65	165.43 ± 5.60*	176.43 ± 5.03*
Weight (kg)	59.72 ± 7.18	54.50 ± 4.25*	65.04 ± 5.33*
Body Fat %	10.04 ± 5.7	14.60 ± 4.71*	5.48 ± 1.10*

*Statistically different between groups, $p < 0.05$

Table 3.2. Performance Parameters

	All (n=14)	Females (n=7)	Males (n=7)
5000m Race Time	-	19:13.00 ± 45.02	-
8000m Race Time	-	-	26:09.00 ± 34.85
SJ0 (cm)	25.91 ± 4.58	22.86 ± 3.50*	28.96 ± 3.33*
CMJ0 (cm)	27.75 ± 4.83	24.69 ± 3.94*	30.81 ± 3.52*
SJ0 Asymmetry %	4.45 ± 2.20	3.84 ± 2.06	4.92 ± 2.19
CMJ0 Asymmetry %	7.91 ± 6.10	7.96 ± 8.23	7.88 ± 3.68

*Statistically different between groups, $p < 0.05$

Table 3.3. Correlation Matrix for all Athletes

All Athletes	Age	Height	Weight	% Body Fat	SJ0	CMJ0	SJ Asy%	CMJ Asy%
Age	-							
Height	0.355	-						
Weight	0.241	0.841*	-					
% Body Fat	0.437	0.450*	-0.437*	-				
SJ0	0.180	0.503	0.592*	-0.602*	-			
CMJ0	0.191	0.383	0.552*	-0.605*	0.934*	-		
SJ0 Asymmetry %	0.446	0.083	0.255	-0.011	-0.011	-0.046	-	
CMJ0 Asymmetry %	0.161	0.052	-0.119	-0.177	-0.179	-0.310	0.542*	-

*Statistically significant, $p < 0.05$

Table 3.4. Correlation Matrix for Female Athletes

Women	Age	Height	Weight	% Body Fat	SJ0	CMJ0	SJ Asy%	CMJ Asy%	Race
Age	-								
Height	0.333	-							
Weight	0.472	0.542	-						
% Body Fat	0.466	0.437	0.782*	-					
SJ0	0.144	-0.241	-0.231	-0.243	-				
CMJ0	0.045	-0.477	-0.400	-0.210	0.928*	-			
SJ0 Asymmetry %	0.284	0.514	0.782*	0.396	-0.292	0.505	-		
CMJ0 Asymmetry %	0.004	0.488	0.174	-0.371	-0.123	0.434	0.606	-	
Race	0.512	0.061	0.444	0.651	-0.553	0.406	0.361	-0.294	-

*Statistically significant, $p < 0.05$

Table 3.5. Correlation Matrix for Male Athletes

Men	Age	Height	Weight	% Body Fat	SJ0	CMJ0	SJ Asy%	CMJ Asy%	Race
Age	-								
Height	0.861*	-							
Weight	0.456	0.787*	-						
% Body Fat	0.014	-0.125	-0.500	-					
SJ0	0.091	0.382	0.556	0.100	-				
CMJ0	0.045	0.290	0.658	-0.390	0.842*	-			
SJ0 Asymmetry %	0.770*	-0.596	-0.196	-0.324	-0.040	0.108	-		
CMJ0 Asymmetry %	-0.611	0.856*	0.785*	-0.044	-0.479	0.300	0.633	-	
Race	0.071	0.204	-0.043	0.076	-0.263	0.460	-0.246	-0.241	-

*Statistically significant, $p < 0.05$

Discussion

Physical Characteristics

As shown by the demographics, all athletes were similar in age, as they were collegiate athletes. On average, the males were 11 cm taller than the females and weighed 10.5 kg more. These results are to be expected due to the typical size differences between males and females. Fuster et al. (1998) reported similar sex differences in their study; the males were taller and weighed more than the females (Fuster et al., 1998). Additionally, in this study the females had more body fat percent than the males, by 9.1%. Friedrich and Rust (2014) also reported female distance runners having a greater percent body fat percentage (28.4%) than male distance runners (17.5%) (Friedrich et al., 2014).

Performance Parameters

On average, the males' SJ0 height was 6.1 cm higher than the females. The male's CMJ0 height was also higher than the females' by 6.1 cm. Similarly, in a study by McMahon et al. (2017), the male subjects had a 24% higher CMJ0 height than the female subjects (McMahon et al., 2017). Force development is a major contributor to jump height. Since males may be capable of activating more motor units to produce more force and due to their larger muscle cross-sectional area, they typically have higher jump heights than females (Rice et al., 2017).

The males' average asymmetry percentage for SJ0 (4.92 ± 2.19%) was slightly higher than the females' (3.84 ± 2.06%). Conversely, the females' average asymmetry percentage for CMJ0 (7.96 ± 8.23%) was slightly higher than the males' (7.88 ± 3.68%). The results of this current study differ from those of Bailey et al (2015). Bailey and colleagues found statistically different asymmetry levels between males and females, concluding that females demonstrated higher asymmetry levels than males (Bailey et al., 2015). However, the asymmetry values in this current study are relatively low, indicating that the athletes had relatively symmetric force production capabilities. This is beneficial as substantial jump asymmetry is thought to have a negative effect on injury risk and performance; therefore, the less asymmetry, the better (Furlong et al., 2018). Additionally, the large standard deviations indicate that this characteristic varied greatly for each athlete.

The current study did not reveal any statistically significant correlations between jump height and race time or between jump asymmetry and race time. Although not statistically significant, there was a negative relationship between SJ0 height and 5,000-meter race time (r = -0.553) in the female athletes. Conversely, Hudgins et al. (2013) did find significant correlations between jump performance and 3,000-meter running time (r = 0.72) as well as 5,000-meter running time (r = 0.71). However, the study by Hudgins et al. (2013) included 33 NCAA Division 1 athletes and a different type of jump test. Additionally, Sinnett et al. (2003) found that SJ height, CMJ height, and percent body fat were significantly correlated with 10,000-meter race time in their sample of thirty-six trained runners (Sinnett et al., 2003). The different sample size, training status of the subjects, and jump protocol could account for the disparities in results compared to the current study. As previously stated, there is limited research on the relationship between jump ability and long distance race performance and it is therefore difficult to compare studies.

Conclusion

The results of this study did not show statistically significant relationships between jumping ability and race-time in this collegiate cross-country team. The athletes were capable of maintaining a minimal amount of kinetic asymmetry during the jump tests. It is possible that no significant correlations were found between jump height, jump asymmetry, and race-time because the asymmetry values were minimal. Additional research would be required to further investigate this relationship due to the small sample size in this current study.

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Chapter 4.

THE EFFECTS OF A STRENGTH TRAINING PROGRAM ON JUMP HEIGHT AND ASYMMETRY IN COLLEGIATE RUNNERS

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The effects of a strength training program on jump height and asymmetry in collegiate runners

Abstract

Research has shown that strength training can help to improve lower limb asymmetries. However, little research has examined the effects of strength training on jump asymmetries in collegiate runners. The purpose of this study is to examine the effects of a strength training program on lower limb asymmetry and jump height in collegiate distance runners and sprinters. As part of an athlete monitoring program, sixteen (6 sprinters, 10 distance runners) athletes participated in two testing sessions that were 21 weeks apart. During the study, they also participated in a resistance training program. The female distance runners statistically improved their SJ0 height, CMJ0 height, CMJ0 asymmetry percentage, and body fat percentage. Overall, these findings show that there are potential benefits of a resistance training program for collegiate runners.

Introduction

Evidence indicates promising effects of a strength training regimen on endurance running performance through improving running economy (Beattie, Carson, Lyons, Rossiter & Kenny, 2017; Johnston, Quinn, Kertzer & Vroman, 1997; Storen, Helgerud, Stoa & Hoff, 2008). Alterations in running economy as a result of strength training is most likely due to enhanced mechanical efficiency, thus less work for a given pace (Jones & Bampouras 2007; Saunders et al., 2004). There is also evidence that strength training can help to improve lower limb asymmetry, which can affect running economy (Beattie et al., 2017). The purpose of this study is to examine the effects of a strength training program on lower limb asymmetry and jump height in collegiate distance runners and sprinters.

Possible mechanisms of lower limb asymmetry may be imbalances in strength, structure, or gait, or a combination of these factors (Zifchock et al., 2008). Lower limb muscular strength plays a key role in stabilizing the body in order to better absorb impactful forces and produce peak forces that will propel the body forward while running. Bazyler et al (2014) found a strong inverse relationship between squat isometric strength and lower limb asymmetry, indicating that weaker athletes had more asymmetry. Additionally, the weaker athletes who participated in the 7-week bilateral strength training intervention (squats) were able to decrease their asymmetry. Hudgins et al. (2013) found strong, positive correlations between jumping ability and running performances in the 60, 100, 200, 800, 3,000, and 5,000 meter races. Given this relationship, it would be of interest to examine whether a strength training program improves jumping ability and symmetrical force producing capabilities of runners.

This study is important to sport science because, despite the potential positive effects, strength training is still an uncommon modality in the distance community. This study could provide further convincing evidence to running coaches to incorporate a strength training component into their athletes' regimen.

Methods

Athletes

The athletes were 16 trained male and female collegiate distance runners and sprinters (18-22 years) from an NAIA University Cross-Country and Track & Field team. All athletes were part of East Tennessee State University's Sports Science athlete monitoring program. To be included, athletes met the following inclusion criteria: free of cardiovascular or musculoskeletal injury or illness, completed all tasks of both testing sessions, and participated in the strength training program. All athletes previously consented to allow their monitoring data to be included in the ETSU Sport Science repository system and to be used in this study. The study was approved by the University IRB (c1120.9sd).

Procedures

On the first day of the study, athletes arrived at the sport science lab in the morning. Each athlete provided a urine sample to ensure adequate hydration status before participating in the series of baseline tests. Their age, height, and body mass were then recorded. Lange skinfold calipers (Beta Technology Inc., Cambridge, MA, USA) were used to measure skinfolds at each of the 7 sites (triceps, subscapular, chest, midaxillary, suprailiac, abdomen, and thigh) following ACSM guidelines (ACSM, 2010). The Jackson & Pollock 7-site skinfold equations for men and women were used to calculate body density and then body fat percentage (Jackson, Pollock, and Ward, 1978; Jackson, Pollock, and Ward, 1980).

Athletes proceeded to complete a standardized warm-up of 25 jumping jacks, 5 mid-thigh pulls (MTP) at 20kg, and then 3x5 MTP at 40kg for females and 60kg for males. They then performed two types of jumps: a static jump (SJ) and a countermovement jump (CMJ), while holding a near-weightless pipe on their shoulders. All jump tests were performed on a platform with dual force plates (Rice Lake Weighing Systems, Rice Lake, WI). For the SJ, athletes descended into a squat position until they reached a 90° knee angle. Once stable, the tester shouted "3, 2, 1…jump" and the athlete jumped straight up. Athletes performed two warm-up jumps at 50% and 75% of perceived maximal effort before performing at least 2 maximal jumps. Athletes completed more than 2 maximal jumps if the difference between the two previous jumps was $\geq$ 2 centimeters. Following SJ, athletes performed CMJ. For CMJ, athletes stood upright on the platform until the tester shouted "3, 2, 1…jump", then performed a countermovement by dropping down to their preferred depth and then jumping straight up. Similar to SJ, athletes performed one 50% and one 75% warm-up jump before completing at least 2 maximal CMJ. If the difference between the two jumps was ≥ 2 centimeters, the athlete performed additional jumps. Jump data was analyzed using LabView 2010 software (National Instruments, Austin, TX) and Microsoft Excel (Microsoft Corporation, Redmond, WA, version 16.25). The 2 highest SJ and CMJ were used to calculate jump height and asymmetry percentage for each. Asymmetry percentages were calculated as a percent, using net impulse from the left and right side as follows: (Highest-Lowest) / (Highest + Lowest)*100.

After baseline testing was complete, all athletes participated in a 21-week strength and conditioning program in addition to their running regimen shown in **Figure 4.2** and **Figure 4.3**. The strength programs, created by the researcher and approved by the supervisor, followed a single-factor, block periodized design (Stone et al., 2021). The athletes (distance runners) on the Cross-Country team competed in the 2019 cross-country season. After 21 weeks, athletes returned to the sport science lab at the same time of day to perform the same series of tests. See **Figure 4.1** for study design.

Figure 4.1. Study Design

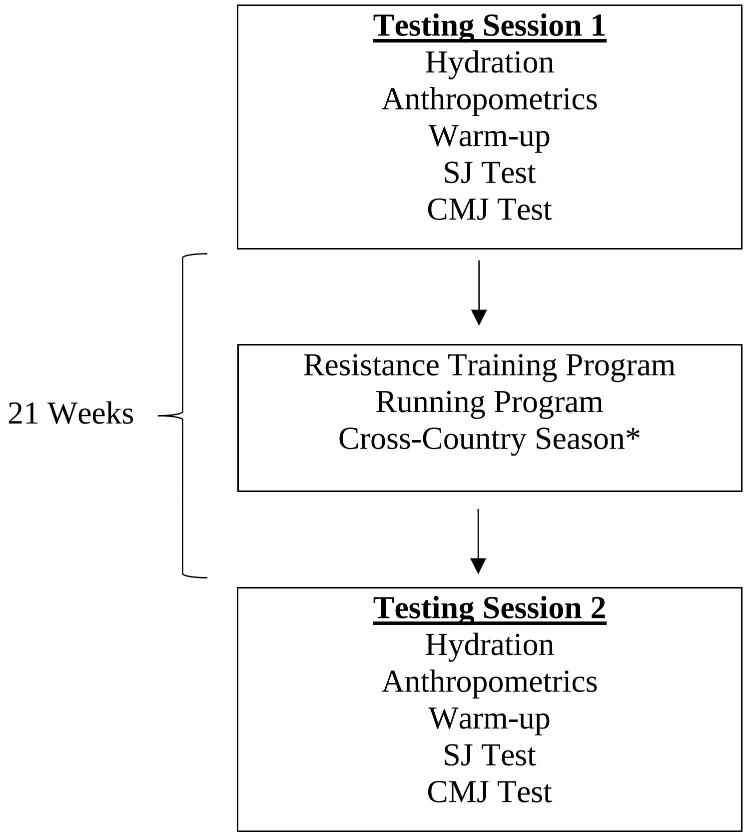

Figure 4.2. Resistance Training Program for Distance Runners

PHASE	WEEK	DAY 1	% 1RM	DAY 2	% 1RM
BASIC STRENGTH	1	3x5	77%	3x5	70%
	2	3x5	77%	3x5	72%
	3	3x5	80%	3x5	75%
MAX STRENGTH	4	3x5	82%	3x5	75%
	5	3x5	80%	3x5	70%
	6	3x5	85%	3x5	77%
STRENGTH-SPEED	7	3x4	85%	3x4	77%
	8	3x4	87%	3x4	80%
	9	3x4	75%	3x4	70%
COMPETITION/TAPER	10	2x3	90%	2x3	70%
	11	2x2	80%	2x2	65%
	12	3x2	90%	3x2	65%
	13	2x2	80%	2x2	60%
REST	14	N/A	N/A	N/A	N/A
RETURN TO FITNESS	15	3x8	80%	3x8	70%
	16	3x8	80%	3x8	70%
	17	3x8	82%	3x8	75%
	18	3x8	82%	3x8	75%
MAX STRENGTH	19	4x3	77%	4x3	70%
	20	3x3	80%	3x3	72%
	21	3x3	82%	3x3	75%

Figure 4.3. Resistance Training Program for Sprinters

Phase	Week	Day 1	% 1RM	Day 2	% 1RM
RETURN TO FITNESS	1	3x10	70%	3x10	65%
	2	3x10	70%	3x10	65%
STRENGTH ENDURANCE	3	3x8	75%	3x8	70%
	4	3x8	75%	3x8	70%
	5	3x8	70%	3x8	65%
MAX STRENGTH	6	3x3	85%	3x3	75%
	7	3x5	80%	3x5	75%
	8	3x5	83%	3x5	77%
	9	3x3	85%	3x3	80%
STRENGTH-SPEED	10	3x4	75%	3x4	70%
	11	3x3	80%	3x3	75%
	12	3x3	85%	3x3	80%
SPEED-STRENGTH	13	4x3	70%	4x3	65%
	14	4x3	70%	4x3	65%
	15	3x3	75%	3x3	70%
	16	3x3	80%	3x3	75%
	17	3x2	85%	3x2	80%
COMPETITION/TAPER	18	3x5	75%	3x5	70%
	19	3x3	85%	3x3	80%
	20	3x3	75%	3x3	70%
	21	3x3	75%	3x3	70%

Statistical Analysis

A Shapiro-Wilks normality test was performed to determine if the data were normally distributed using R (version 4.0.4). Data from the athlete's demographics and performance parameters were analyzed using Microsoft Excel (Microsoft Corporation, Redmond, WA, version 16.25) by calculating averages and standard deviations. To determine within and between group differences for dependent variables, paired sample t-tests and independent sample t-tests were calculated. For all tests, the alpha level was set at $p \leq 0.05$.

Results

Physical Characteristics

All athlete demographics are shown in **Table 4.1**. The athletes consisted of 6 sprinters (four males and two females) and 10 distance runners (5 males and 5 females), ranging from 18 to 22 years old. On average, the sprinters were heavier than the distance runners at testing session 1 (sprinters: 66.0 ± 1.0 kg; distance: 54.4 ± 4.3 kg) and testing session 2 (sprinters: 66.8 ± 1.2 kg; distance: 54.2 ± 4.3 kg). Neither group had statistically significant changes in body weight from testing session 1 to testing session 2.

Additionally, when stratified by sex in **Table 4.2** and **Table 4.3**, the female sprinters were heavier than the female distance runners at testing session 1 (female sprinters: 66 ± 1.0 kg; female distance: 54.4 ± 4.3 kg) and testing session 2 (female sprinters: 66.9 ± 1.2 kg; female distance 54.2 ± 4.3 kg) and the male sprinters were heavier than the male distance runners at testing session 1 (male sprinters: 79.5 ± 7.3 kg; male distance: 69.3 ± 4.4 kg) and testing session 2 (male sprinters: 80.2 ± 6.7 kg; male distance: 68.8 ± 4.0 kg). On average, the distance runners had a lower body fat percentage than the sprinters at testing session 1 (distance: 24.6 ± 4.8%; sprinters: 29.6 ± 0.6%) and testing session 2 (distance: 14.5 ± 5.3%; sprinters: 20.0± 4.3%). When stratified by sex, the female distance runners had a lower body fat percentage than the female sprinters at testing session 1 (female distance: 24.6 ± 4.8%; female sprinters: 29.6 ± 0.6%) and testing session 2 (female distance: 14.5 ± 5.3%; female sprinters: 20.0± 4.3%). Similarly, the male distance runners had a lower body fat percentage than the male sprinters at testing session 1 (male distance: 6.5 ± 1.4%; male sprinters: 8.1 ± 0.9%) and testing session 2 (male distance: 5.7 ± 0.7%; male sprinters: 6.4 ± 1.4%).

Performance Parameters

All athletes' performance parameters are displayed in **Table 4.4**. On average, the sprinters had significantly higher SJ0 (25.0 ± 2.0 cm) and CMJ0 (28.6 ± 0 .6 cm) heights than the distance runners (SJ0: 19.7 ± 3.3 cm; CMJ0: 20.9 ± 3.5 cm) at testing session 1. Although not significant, the distance runners had improvements in all performance parameters from testing session 1 to testing session 2.

Performance parameters for male athletes only are displayed in **Table 4.5.** The male sprinters had significantly higher CMJ0 and SJ0 heights than the male distance runners at both testing sessions. There was little change in CMJ0 and SJ0 heights in between sessions for both groups. Although not statistically significant, the male distance runners improved both jump asymmetry variables between testing session 1 and testing session 2.

Performance parameters for female athletes only are displayed in **Table 4.6.** The female sprinters had significantly higher CMJ0 heights (27.6 ± 0.6 cm) than the female distance runners (21.0 ± 3.5 cm) at testing session 1. The female distance runners significantly increased their average SJ0 height from testing session 1 (19.7 ± 3.3 cm) to testing session 2 (23.4 ± 3.6 cm) and their average CMJ0 height from testing session 1 (20.9 ± 3.5 cm) to testing session 2 (25.0 ± 4.4 cm). The female distance runners also significantly decreased their CMJ0 asymmetry percentage from testing session 1 (13.2 ± 10.4%) to testing session 2 (8.9 ± 9.6%).

Table 4.1 Athlete demographics and body composition for testing sessions 1 and 2

	Sprinters (n=6)			Distance Runners (n=10)		
	T1	T2	P Value	T1	T2	P Value
Age (years)	19.5 ± 1.5	20 ± 1	0.175	19.4 ± 1.0	20 ± 1.3	0.005
Height (cm)	174.1 ± 9.1	173.5 ± 8.5	0.312	167.2 ± 6.7	167.2 ± 5.7	0.329
Weight (kg)	66 ± 1.0*	66.6 ± 1.2*	0.142	54.4 ± 4.3*	54.2 ± 4.3*	0.122
% Body Fat	29.6 ± 0.6	20.00 ± 4.3	0.080	24.6 ± 4.8	14.5 ± 5.3	0.010

*Significantly different between groups, $p < 0.05$

Table 4.2 Male demographics and body composition for testing sessions 1 and 2

Males	Sprinters (n=4)			Distance Runners (n=5)		
	T1	T2	P Value	T1	T2	P Value
Age (years)	19.8 ± 1.3	19.8 ± 1.3	0.391	18.8 ± 0.7	19.4 ± 1.0	0.070
Height (cm)	181.1 ± 3.8	181.1 ± 3.6	0.703	177.2 ± 4.2	177.3 ± 4.2	0.284
Weight (kg)	79.5 ± 7.3	80.3 ± 6.7	0.353	69.3 ± 4.4	68.8 ± 4.0	0.256
% Body Fat	8.1 ± 0.92	6.4 ± 1.4	0.039	6.5 ± 1.4	5.7 ± 0.7	0.128

Table 4.3 Female demographics and body composition for testing sessions 1 and 2

Females	Sprinters (n=2)			Distance Runners (n=5)		
	T1	T2	P Value	T1	T2	P Value
Age (years)	19.5 ± 1.5	19.5 ± 1.5	0.5	19.4 ± 1.0	20.0 ± 1.3	0.070
Height (cm)	174.1 ± 9.1	173.5 ± 8.5	0.5	167.2 ± 5.7	167.2 ± 5.7	1.000
Weight (kg)	66 ± 1.0*	66.9 ± 1.2*	0.111	54.4 ± 4.3*	54.2 ± 4.3*	0.242
% Body Fat	29.6 ± 0.6	20.0 ± 4.3	0.234	24.6 ± 4.8	14.5 ± 5.3	0.002

*Significantly different between groups, $p < 0.05$

Table 4.4 Performance parameters for all athletes, testing sessions 1 and 2

	Sprinters			**Distance Runners**		
	T1	T2	P Value	T1	T2	P Value
SJ0 (cm)	25.0 ± 1.95*	24.1 ± 1.8	0.545	19.7 ± 3.29*	23.4 ± 3.6	0.096
CMJ0 (cm)	27.6 ± 0.6*	26.8 ± 1.2	0.372	20.9 ± 3.5*	25.0 ± 4.4	0.099
SJ0 Asymmetry Percentage %	3.4 ± 2.2	5.4 ± 3.26	0.276	6.4 ± 4.7	4.5 ± 2.2	0.416
CMJ0 Asymmetry Percentage %	8.0 ± 6.4	5.7 ± 2.1	0.444	11.9 ± 8.3	7.9 ± 6.1	0.063

*Significantly different between groups, $p < 0.05$

Table 4.5 Male performance parameters for testing sessions 1 and 2

Males	Sprinters (n=4)			Distance Runners (n=5)		
	T1	T2	P Value	T1	T2	P Value
SJ0 (cm)	43.9 ± 5.7*	43.4 ± 4.4*	0.765	30.3 ± 3.02*	30.5 ± 3.8*	0.864
CMJ0 (cm)	47.8 ± 7.2*	49.2 ± 6.7*	0.270	33.8 ± 2.1*	33.3 ± 3.3*	0.523
SJ0 Asymmetry Percentage %	2.6 ± 2.0	4.8 ± 1.8	0.240	5.1 ± 1.9	4.9 ± 2.2	0.443
CMJ0 Asymmetry Percentage %	8.8 ± 6.3	6.9 ± 1.0	0.671	10.6 ± 5.0	7.9 ± 3.7	0.509

*Significantly different between groups, $p < 0.05$

Table 4.6 Female performance parameters for testing sessions 1 and 2

Females	Sprinters (n=2)			Distance Runners (n=5)		
	T1	T2	P Value	T1	T2	P Value
SJ0 (cm)	25.0 ± 1.95	24.1 ± 1.8	0.111	19.7 ± 3.3	23.4 ± 3.6	0.045
CMJ0 (cm)	27.6 ± 0.6*	26.8 ± 1.2	0.455	20.9 ± 3.5*	25.0 ± 4.4	0.015
SJ0 Asymmetry Percentage %	5.13 ± 1.4	4.4 ± 0.18	0.851	7.6 ± 6.1	3.84 ± 2.1	0.178
CMJ0 Asymmetry Percentage %	6.6 ± 6.3	3.4 ± 1.6	0.619	13.2 ± 10.4	8.9 ± 9.6	0.006

*Significantly different between groups, $p < 0.05$

Discussion

Physical Characteristics

As shown by the demographics, all athletes were similar in age due to the fact that they were collegiate athletes. The sprinters were 11.6 kg heavier than the distance runners at testing session 1 and 12.6 kg heavier at testing session 2. Additionally, the sprinters had a higher body fat percentage at testing session 1 by 5.0% and at testing session 2 by 5.5%. A higher body mass in sprinters is to be expected as sprinters characteristically have more muscle mass and also different fiber type profile than distance runners. Type II fibers are typically larger than Type I fibers and typically are more prevalent in the quadriceps of sprinters and respond with greater increases in CSA during resistance and sprint training. Thus, along with more muscle mass the difference between sprinters and distance runners may be partly due to the increased Type II muscle fiber content needed for maximal force output (Fukatani et al. 2020; Hamner et al., 2010). Similarly, Spenst et al. (1993) also reported that muscle mass was greater in track and field power athletes than in the long distance runners.

Between the testing sessions, both sprinters and distance runners decreased their body fat percentage by 9.6% (p value = 0.08) and 10.13% (p value = 0.01), respectively. Additionally, the timing of the testing sessions may explain these results. Testing session 1 took place when the athletes arrived back on campus after their summer break. Although they were given a summer running and strength training regime, due to NAIA regulations, it was difficult to control for and monitor adherence. Inherently, once the athletes began regularly scheduled and supervised training, their body composition improved.

While there was a substantial decrease in body fat percentage in the distance runners, there were no meaningful changes in body mass. This indicates that the strength training likely helped to reduce body fat and increase lean body mass, while not significantly increasing body mass. This is ideal as there are potential advantages of low body mass in endurance running. Ground reaction forces and heat production and storage are higher in larger runners, putting them at a disadvantage (Berg et al., 2013).

Performance Parameters

The jump tests performed by the athletes showed that the sprinters had higher average SJ0 and CMJ0 heights than the distance runners at both testing sessions. This is consistent with most literature as sprinters tend to have more muscle mass and a greater CSA of type II fibers than distance runners and can therefore produce more force (Hammer et al., 2010).

On average, the distance runners improved their SJ0 height by 3.76 cm and CMJ0 height by 4.06 cm. These results coincide with previous research. Taipale et al (2010) also found that CMJ0 height increased after resistance training. In their study, 28 recreational endurance runners completed eight-weeks of either maximal strength, explosive strength or circuit training. The maximal and explosive strength groups saw significant increases in CMJ0 height. Additionally, the maximal and explosive strength groups had substantial improvements in running velocity at $\dot{V}O_2max$ and running economy (Taipale et al., 2010). This further demonstrates the potential benefit of strength training to endurance performance.

At both testing sessions, the distance runners had higher asymmetry levels than the sprinters. This could be due to the lower strength level of the distance runners, which again agrees with Bailey's study that weaker athletes display more asymmetries than stronger ones (Bailey et al., 2015). Overall, both male and female distance runners had decreases, or improvements, in their asymmetry, whereas the male sprinters did not. This might be explained by the baseline strength levels of the groups, the male sprinters being the strongest group in the study. Bazyler et al. (2014) found that their weaker individuals had higher (isometric squat) asymmetry scores but were able to statistically improve their asymmetry with strength training (Bazyler et al., 2014). However, the stronger individuals had lower baseline asymmetry scores and did not statistically decrease their asymmetry after the strength training intervention; the researchers concluded that strength may only decrease lower limb asymmetries to a point (Bazyler et al., 2014).

The female distance runners showed the most improvements in all performance parameters. They improved SJ0 height, CMJ0 height, CMJ asymmetry percentage, and body fat percentage. This may be due to the fact that at testing session 1 they had the lowest jump heights, indicating that they were the weakest group in the study, as well as some of the highest asymmetry values compared to the other groups. Wetmore et al (2020) found that weaker individuals improved at a greater rate than stronger individuals in SJ0 and CMJ0 height after just 7 weeks of strength training. This also agrees with the findings from Bazyler et al. (2014), that there seems to be an inverse relationship between maximum strength and lower limb asymmetry that can be augmented with strength training (Bazyler et al., 2014).

Conclusion

The results of this study show that there are several potential benefits of a strength training program applicable to collegiate runners. The distance runners significantly improved their body composition without statistically significant changes in overall body weight. Furthermore, the female distance runners gained the most benefits with the most significant improvements in all of the performance parameters.

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Chapter 5. Conclusion

In conclusion, we did not find statistically significant relationships between jump height and race performance or between jump asymmetry and race performance in this collegiate cross-country team. This contradicts the available research, as there are studies linking jumping ability with running performance. Differences between studies may be related to trained state differences or method differences. These athletes were, however, able to maintain relatively low levels (SJ: 4.5 ± 2.2%; CMJ: 7.9 ± 6.1%) of kinetic asymmetry during the jump tests. This can be considered as beneficial because research has shown that high levels of lower limb asymmetry (> 12%) can negatively affect performance and injury risk.

The 21-week strength training intervention in the current study resulted in positive effects for body composition and jump parameters in the sprinters and distance runners. In particular, the female distance runners had statistically significant improvements in jump height, jump asymmetry, and body fat percentage, without significant changes in body weight. These results provide more evidence of the potential benefits runners could gain from strength training; specifically, the distance runners, as strength training is still not commonly incorporated in long-distance training.

This study was limited by a small sample size. Further studies should examine the relationship between jump parameters and long-distance race performance in a larger sample. These types of investigations would contribute to sport science and coaching, as to whether jumping ability and asymmetry could be used as a predictor of running performance. Jumping tests as part of athlete monitoring would be a very practical method for coaches to assess the needs of individual athletes when creating their training programs. Although the sample size was relatively small (16 athletes: six sprinters and ten distance runners) the results are in general agreement with the literature concerning strength training and running. Other studies withing this topic used different jumping protocols than used in this current study, and it is therefore difficult to compare results.

Additionally, future research should examine the effects of a year-round strength training program on jump asymmetry and performance in runners because this current study only considered 21 weeks of strength training. Studies have shown that strength training can help to reduce asymmetry, however a more long-term approach might be necessary to better quantify potential improvements. It would also be of interest to investigate athletes with existing low asymmetry levels as to the potential for improvements in asymmetry and performance occurring over longer training periods (i.e. year(s)) or whether strength training can affect asymmetry to a certain point.

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Appendix: Data Collection Sheets

Milligan XC/Track & Field Hydration

Date: _________

Name							
Last	First	Trial 1		Trial 2		Trial 3	
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.
		1.	1.	1.	1.	1.	1.

Milligan Athlete Demographics

Athlete	Age	Height (cm)	Mass (kg)

Milligan Body Composition

Athlete	Age	Triceps	Subscap	Midaxillary	Chest	Suprailiac	Abdomen	Thigh	Sum	Density	% Body Fat

FORCE PLATE: RC Jump **DATE:**

	Previous Average			SJ0							SJ20						
ATHLETE	TESTER	SJ0	SJ20	1	2	3	4	5	6	7	1	2	3	4	5	6	7

	Previous Average			CMJ0							CMJ20						
ATHLETE	TESTER	CMJ0	CMJ20	1	2	3	4	5	6	7	1	2	3	4	5	6	7

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