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The Relationships of Physiological and Strength Variables to Run Performances

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Recommended Citation

The Relationships of Physiological and Strength Variables to Run Performances

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A dissertation

presented to

the faculty of the Department of Exercise and Sport Science

In partial fulfillment

of the requirements for the degree

Doctor of Philosophy in Sport Physiology and Performance

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by

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August 2015

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Keywords: 3 minute all out run, 3km time trial, critical speed, vertical jump, strength, $\dot{V}O_2max$

ABSTRACT

The Relationships of Physiological and Strength Variables to Run Performances

by

Jana E. Hollins

Monitoring progress of athletes is an essential component of the training process. Collegiate distance running coaches often use field tests to assess progress because of a lack of time and resources to do laboratory testing. The purpose of this dissertation was to examine the relationships between physiological and strength variables measured in a laboratory and field testing measures in collegiate distance runners. Collegiate distance runners completed a series of tests in the Sport Science laboratory at East Tennessee State University to obtain physiological and strength parameters, such as $\dot{V}O_2max$ and vertical jump height. The athletes then completed one of two field tests (either a 3 km time trial or a 3 minute all out run test). There were strong correlations between the laboratory measures and the field test performances. These results indicate that strength is an important factor in run performance. Also, a 3 km time trial and a 3 minute all out run test are suitable for athlete monitoring.

DEDICATION

This dissertation is dedicated to my parents. Thank you for all your love, support, and commitment through the years. Thank you for spending so many hours traveling to and watching all the various sporting events and conferences along the way.

This dissertation is also dedicated to Vincent. Thank you for your love and patience during this process. Your commitment to pursuing your dream has been a huge encouragement to me.

ACKNOWLEDGEMENTS

To my chair, Dr. Stone, thank you for your guidance and insight throughout the entire program. To the rest of my committee, Dr. Ramsey, Dr. Sato, and Dr. Triplett, thank you for being so helpful, answering questions at the drop of a hat, and giving advice along the way.

I would also like to thank the other graduate students in the Exercise and Sport Science Department at ETSU for all the help and hard work in the Sport Science Lab. I especially want to thank Brad Alban for listening to my ideas, helping sort out scheduling, and being there every day.

Finally, I want to thank Chris Layne and the other cross country track and field staff members at Milligan College for giving me the opportunity to work with you the last 3 years. I have learned a tremendous amount and truly enjoyed my time with all of you.

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CHAPTER 1

INTRODUCTION

Athlete monitoring (regular athlete testing and quantifying training loads) using a structured monitoring program has been beneficial to athletes and coaches in improving perceptions of performance (Reed, 2014). Furthermore, monitoring various aspects of an athlete's training is essential to increasing performance and reducing the risk of overtraining or undertraining (Stone, Stone, & Sands, 2007). The needs of the sport, along with the coach, will dictate what variables are monitored. Most distance running coaches view maximal oxygen consumption as an important factor in success of their athletes. However, many coaches do not have the time or resources to measure maximal oxygen consumption. Furthermore, maximal oxygen consumption, by itself, has been shown to be a poor predictor of run performance among advanced and elite athletes (Daniels, Yarbrough, & Foster, 1978; Jones, 1998).

While many distance running coaches use race performance or field tests, such as time trials, to monitor the progress of athletes over the course of a season, there is little research investigating the relationships of time trials or other athlete monitoring tools and laboratory measured variables that can influence performance in collegiate distance runners. Many factors have been identified that can influence run performance (Bassett & Howley, 2000; Billat, 2001; Powers & Howley, 2012; Saunders, Pyne, Telford, & Hawley, 2004). These factors include maximal oxygen consumption ($\dot{V}O_2max$), lactate threshold (LT), running economy (RE). The adaptive interaction of running economy, oxygen consumption, and lactate threshold has been noted by Billat and Koralsztein (1996) to alter running speed. Increasing running speed, to increase race performance, is the goal of a coach.

There are many ways to increase running speed such as increasing strength levels to improve running economy (Johnston, Quinn, Kertzer, & Vroman, 1997; Saunders et al., 2006; Storen, Helgerud, Stoa, & Hoff, 2008). These improvements in strength can be monitored via measures of maximum strength (Dumke, Pfaffenroth, McBride, & McCauley, 2010; Kraska et al., 2009; Millet, Jaouen, Borrani, & Candau, 2002) or dynamic relative strength in vertical jumps (Balsalobre-Fernández, Tejero-González, & del Campo-Vecino, 2014; Barnes, Mcguigan, & Kilding, 2014; Kraska et al., 2009). Because changes in strength levels can change running economy, it is important to understand the relationships between strength and run performance when developing a training plan for distance running athletes.

The purpose of this dissertation was to examine the relationships between field tests and laboratory tests in an effort to provide insight into athlete monitoring tools for collegiate distance runners. Specifically, the purpose for the first study was to examine the relationships between maximal oxygen consumption, body composition, maximum strength measures, relative strength measures, coach rank, and a 3 km time trial in NCAA Division I collegiate distance runners. The purpose for the second study was to examine the relationships between maximal oxygen consumption, body composition, relative strength measures, and a 3 minute all out run test in NAIA collegiate distance runners.

<u>Operational Definitions</u>

1. Maximal oxygen consumption: maximum amount of oxygen that can be consumed in one minute

2. Running economy: amount of energy needed to run at a given pace

3. Lactate threshold: work rate at which the blood lactate concentration begins to rise exponentially

4. Strength: ability to produce force

5. Isometric peak force: maximum amount of force that was produced in an isometric mid-thigh pull

6. Force at 50 ms: maximum force that was produced at 50 milliseconds

7. Allometrically scaled isometric peak force: maximum amount of force that was produced in an isometric mid-thigh pull scaled to the 2/3 power

8. Allometrically scaled force at 50ms: maximum force that was produced at 50 milliseconds scaled to the 2/3 power

9. Critical speed: the fastest running speed that can be sustained for a given distance

CHAPTER 2

REVIEW OF LITERATURE

Distance Running

The highest competitive level for distance running is the Olympics. Running events have been competed in every modern Olympics since 1896 for men and 1928 for women (IOC, 2013). Various distances have been competed in each Olympics based on what is voted in or out of competition. The current list of Olympic distance running events includes 800m, 1500m, 3000m steeplechase, 5000m, 10,000m, and marathon.

Few athletes will compete at the Olympic level. However, many athletes in the United States have had the opportunity to compete at the collegiate level because of collegiate athletic governing bodies: National Collegiate Athletic Association (NCAA) and National Association of Intercollegiate Athletics (NAIA). The NCAA began hosting national championships for men in cross country, outdoor track and field, and indoor track and field in 1938, 1921, and 1965, respectively (NCAA, 2015). Women's national championships in the NCAA began in 1981 for cross country, 1982 for outdoor track and field, and 1983 for indoor track and field (NCAA, 2015). The NAIA began hosting national championships men's outdoor track and field in 1952, cross country in 1956, and indoor track and field in 1966 (NAIA, 2005). Women's championships were begun in 1980 for cross country, outdoor track and field, and indoor track and field (NAIA, 2005).

One thing that is common across all competitive levels is the coaches' and athletes' desire to progress and perform well. Several factors have been identified that influence run performance (Bassett & Howley, 2000; Billat, 2001; Millet et al., 2002; Powers & Howley,

2012; Saunders et al., 2004). Those factors include maximal oxygen consumption ($\dot{V}O_2max$),

running economy (RE), and lactate threshold (LT). Coaches design training programs for athletes

in an effort to manipulate the variables mentioned above and improve their performance. The

following will briefly examine factors that influence run performance, as well as testing methods

for monitoring athletes.

<div align="center">

Maximal Oxygen Consumption ($\dot{V}O_2max$)

</div>

Introduction

The maximal amount of oxygen that can be consumed in one minute by an individual has

been termed maximal oxygen consumption, or $\dot{V}O_2max$ (Bassett & Howley, 2000; Powers &

Howley, 2012). $\dot{V}O_2max$ has been a topic of interest for nearly a century, beginning with the

work of Hill and Lupton (1923). Many have studied oxygen consumption in different types of

exercises, different protocols, and different fitness levels (Astrand & Saltin, 1961; Cooper, 1968;

Demarie, Koralsztein, & Billat, 2000; Kang, Chaloupka, Mastrangelo, Biren, & Robertson, 2001;

Midgley, Carroll, Marchant, McNaughton, & Siegler, 2009). Astrand and Saltin (Astrand &

Saltin, 1961) found that maximal oxygen uptake can differ with different types of exercise. For

example in well trained subjects, running uphill resulted in higher maximal oxygen consumption

values than cycling in a seated position (Astrand & Saltin, 1961).

Protocols

Mode of exercise used to determine $\dot{V}O_2max$ for a specific population should be

considered because of the validity of measurement (Doyle & Martinez, 1998; Millet, Vleck, &

Bentley, 2009; Powers & Howley, 2012). In a review completed by Millet, Vleck, and Bentley

(2009), runners generally had higher $\dot{V}O_2max$ values for running protocols than for cycling

protocols. This could be due to the amount of muscle mass being used or the specificity of movement required for cycling. Therefore, runners should be tested with a running protocol not a cycling protocol because of sport specificity.

Kang et al. (2001) studied three different running protocols for obtaining $\dot{V}O_2max$ values: Astrand, Bruce, and Costill/Fox. Untrained men and women and trained men (at least 7 years of training) completed the study (Kang et al., 2001). Each individual completed all three protocols. The Astrand protocol had the speed set at 2.7 m/s, and after the first stage (3 min), grade increased by 2% every stage (2 min). The Bruce protocol had 3 min stages where speed and grade both increased after the initial stage. The Costill/Fox protocol had 2 min stages with the speed set at 4.0 m/s for men and 3.5 m/s for women, as well as grade increasing 2% each stage. The authors found no statistical differences in $\dot{V}O_2max$ values between the protocols but did find that test durations differed (Kang et al., 2001). The Astrand and Bruce protocols were said to have produced optimal test durations (14.5 min and 17.0 min, respectively, in trained men), with the Bruce protocol having a lower, but not statistically different $\dot{V}O_2max$ value (Kang et al., 2001).

Criteria for Determining Max

Criteria for determining $\dot{V}O_2max$ have been debated. A plateau in oxygen consumption, respiratory exchange ratio (RER), heart rate (HR), blood lactate concentration, and rating of perceived exertion (RPE) have all been used to varying degrees as criteria for determining $\dot{V}O_2max$ (Midgley, McNaughton, Polman, & Marchant, 2007). Furthermore, there is little agreement in literature for the degree to which each variable constitutes achieving $\dot{V}O_2max$. Textbooks are no better for agreeing on which variables, and to what degree, constitute achieving $\dot{V}O_2max$. For example, Brooks, Fahey, and Baldwin (2005) suggest using RPE, RER ≥ 1.1,

blood lactate level > 8 mmol, heart rate similar to the age-predicted heart rate maximum (APHRM), or a plateau in $\dot{V}O_2$. Morrow, Jackson, Disch, and Mood (2011) suggested using plateau in $\dot{V}O_2$, RER > 1.1, HR near APMHR. Powers and Howley (2012) suggested in their textbook using a plateau in $\dot{V}O_2$ (< 2.1 ml/kg/min), post exercise blood lactate of > 8 mmol, RER > 1.15, and maybe heart rate, which has been highly debated. Therefore, for the purpose of this dissertation the following criteria were used to determine max: plateau in oxygen consumption, RER ≥ 1.1, heart rate ± 10 bpm of APHRM, 3 minute post exercise blood lactate concentration ≥ 8 mmol/L, and RPE.

Maximal Oxygen Consumption in College Athletes

Maximal oxygen consumption values have been used as a descriptive of endurance athletes (running, cycling, etc.) in a plethora of research. Collegiate distance runners have been described by their maximal oxygen consumption values, as well. Many times coaches have used these numbers to define the athlete as good or bad. While this can be true to some extent, $\dot{V}O_2max$ values probably should be used more often as a measure of fitness level because $\dot{V}O_2max$ values have been shown not to be the best predictor of race performance in homogeneous groups (Daniels et al., 1978; Jones, 1998). Furthermore, $\dot{V}O_2max$ values have been shown to change based on training, which may or may not transfer to improved performance (Daniels et al., 1978; Galbraith, Hopker, Cardinale, Cunniffe, & Passfield, 2014; Jones & Carter, 2000; Knuttgen, Nordesjö, Ollander, & Saltin, 1973).

Another common practice for collegiate athletes is to use a time trial to assign a VDOT, and then training paces. VDOT, a term used as a shortened form of $\dot{V}O_2max$, is an estimated $\dot{V}O_2max$ value based on charts in Daniels' Running formula (2013). Jack Daniels is a famous distance running coach and researcher who has developed charts to estimate $\dot{V}O_2max$ from a

race/performance time. Then training paces can be assign based on the VDOT score. The charts set training paces based on percentages of $\dot{V}O_2$max values. The practice of establishing training paces based off of percentages of $\dot{V}O_2$max values has become a common practice (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999; J. Daniels, 2013; Harman et al., 2008; Kraemer et al., 2004; Magness, 2014).

Running Economy

Running economy is the amount of energy needed to sustain a given submaximal speed (Dumke et al., 2010; Saunders et al., 2004). Running economy has been shown to influence run performance (Bassett & Howley, 2000; Jones, 1998; Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999) and accounted for about 65% of the variation in finishing times in a 10 km race (Conley & Krahenbuhl, 1979). In a review by Saunders et al. (2004), three areas were mentioned that could be manipulated to improve running economy: strength training, altitude exposure, and training in a hot environment. In looking at those areas, only one can be manipulated by all collegiate distance running coaches because of location of their institutions: strength training.

Strength levels have been shown to significantly affect running economy (Johnston et al., 1997; Saunders et al., 2006; Stone et al., 2006; Storen et al., 2008) and, ultimately, running performance (Harman et al., 2008; Hoffman, Kraemer, Fry, Deschenes, & Kemp, 1990; Millet et al., 2002; Paavolainen et al., 1999; Skovgaard et al., 2014; Stone et al., 2006). Maximum strength levels have been measured in runners using a 1 RM (Millet et al., 2002), isometric mid-thigh pull (Kraska et al., 2009), and isometric squat (Dumke et al., 2010). All of these tests can be somewhat time consuming and fatiguing.

Kraska et al (2009) also investigated vertical jumps and found that stronger athletes jump higher. Therefore, vertical jumps can be a useful method of obtaining a relative strength value as it is quicker and less fatiguing than maximal testing. Several studies have used vertical jump testing for runners (Balsalobre-Fernández et al., 2014; Barnes et al., 2014; Cole, Woodruff, Horn, & Mahon, 2006; Kraska et al., 2009). Balsalobre-Fernandez et al. (2014) used countermovement vertical jumps (CMJ) as part of a monitoring program for elite middle and long distance runners. The authors stated that CMJ done weekly, along with other measures, are a valuable athlete monitoring tool for runners (Balsalobre-Fernández et al., 2014).

Vertical jumps can be used to observe changes in strength levels of distance runners. As stated above, improvements in strength levels (increased jump height) may allow for increased performance. Increases in maximum strength have been shown to increase neuromuscular function (Bazyler, Abbott, Bellon, Taber, & Stone, 2015; Stone et al., 2007), which can lead to moving more efficiently and better performance (Paavolainen et al., 1999). Therefore, stronger athletes would have less metabolic stress for a given running speed (Bazyler et al., 2015), indicating a greater running economy than weaker athletes.

<u>Lactate Threshold and Maximal Lactate Steady State</u>

Lactate threshold is another factor that influences run performance (Bassett & Howley, 2000; Farrell, Wilmore, Coyle, Billing, & Costill, 1993) and can change with training (Bassett & Howley, 2000; J. Daniels, 1974; Galbraith et al., 2014; Joyner, 1993; Laursen & Jenkins, 2002). Lactate threshold is often defined as the work rate where the concentration of blood lactate begins to rise exponentially (Brooks et al., 2005; McGehee, Tanner, & Houmard, 2005; Stone et al., 2007). Lactate threshold is often associated with high intensity aerobic exercise because of

the increased reliance on anaerobic mechanisms to provide energy to keep up with metabolic demand (Stone et al., 2007).

Interval training, at or above lactate threshold, has been proven an effective method of increasing the lactate threshold (Billat, 2001). Runners that have a higher lactate threshold can perform at a greater percentage of their $\dot{V}O_2max$ (Brandon, 1995), resulting in better run performances. However, many coaches do not have a direct measure of lactate threshold because of the time consuming nature of the testing. Generally an estimation of the pace at which lactate threshold occurs is based on a percentage of the $\dot{V}O_2max$ (Joyner, 1993).

Maximal lactate steady state may be of more interest to distance runners than lactate threshold. Maximal lactate steady state is the fastest running speed where blood lactate concentration remains stable between ten and thirty minutes for that speed (Beneke, 1995). The velocity at maximal lactate steady state has been used previously to prescribe training in endurance athletes (Billat, Sirvent, Lepretre, & Koralsztein, 2004; Philp, Macdonald, Carter, Watt, & Pringle, 2008). Determination of maximal lactate steady state is also time consuming and can be costly. However, Philp et al. (2008) found that training at the velocity associated with maximal lactate steady state twice a week provide improvements in physiological variables such as lactate threshold, $\dot{V}O_2max$, and maximal lactate steady state.

Maximal lactate steady state has been previously associated with critical power or speed for cycling and running, respectively (Burnley, Doust, & Vanhatalo, 2006; Burnley & Jones, 2007; de Lucas, Dittrich, Junior, de Souza, & Guglielmo, 2012; Pettitt, Jamnick, & Clark, 2012). Critical speed is defined as the fastest speed which can be sustained for a period of time, usually between 10 and 30 minutes (Broxterman, Ade, Poole, Harms, & Barstow, 2013; Pettitt et al., 2012). Research has recently suggested the use of a 3 minute all out run test to determine critical

speed, which is associated with the velocity at maximal lactate steady state (Broxterman et al., 2013; Pettitt et al., 2012; Sperlich, Zinner, Trenk, & Holmberg, 2014). Pettit, Jamnick, and Clark (2012) and Broxterman et al. (2013) found that critical speed could be accurately assessed using a 3 minute all out run test. However, Sperlich et al. (2014) found that a 3 minute all out run test overestimated the velocity at maximal lactate steady state and should not be used to prescribe training. The difference in findings may be due to different populations tested. Pettit et al. (2012) used female collegiate distance runners, while Sperlich et al. (2014) used male, well trained runners ages 20-40 years old.

Field Tests for Monitoring Distance Runners

3 Minute All Out Run Test

The sport of cycling has previously used a 3 min all out test to determine critical power, or the power output that can be sustained for a period of time (Burnley et al., 2006; Vanhatalo, Doust, & Burnley, 2007). However, a 3 minute all out test for running to determine critical speed is fairly new and not widely used for distance running athletes (Broxterman et al., 2013; Kranenburg & Smith, 1996; Pettitt et al., 2012; Sperlich et al., 2014). Critical speed is the upper limit of speed that can be sustained for a period of time, mirroring the definition of critical power in cycling (Kranenburg & Smith, 1996; Poole, Ward, Gardner, & Whipp, 1988). Because few studies have been completed on the 3 minute all out run test, the objective for this section was to closely examine the work that has been done.

Several questions have been proposed about the efficacy of using a 3 minute all out run test for distance runners for everything from determining $\dot{V}O_2max$, velocity at maximal lactate steady state, critical speed, to predicting performance. For example, Kranenburg and Smith

(1996) compared track tests for critical speed and laboratory tests for critical speed in male

distance runners. The researchers found that track runs of about 3, 7, and 13 minutes were better

tools to assess a training program and predict performance compared to laboratory treadmill tests

for critical speed.

Pettit et al. (2012) also studied the efficacy of using a 3 minute all out run test to

determine critical speed, distance covered at speeds above critical speed, and predicting race

performance. The researchers examined the ability of a 3 minute all out run test to predict

performance in female distance runners (Pettitt et al., 2012). The female collegiate distance

runners completed a 3 minute all out run test, graded exercise test and verification for $\dot{V}O_2max$,

and competed in various outdoor distance races (Track - 800m and 1600m, Cross Country –

5000m). The 3 minute all out run test was performed on an outdoor track with each of the

athletes wearing a wrist worn GPS (Pettitt et al., 2012). For the 3 minute all out run, the athletes

were told to "build up to the maximal speed and maintain as fast of a running speed throughout

the entire test" (Pettitt et al., 2012). Also, the researchers did not give the athletes time checks

throughout the test. These instructions are important as providing different instructions may have

an effect on the outcome.

Pettit and colleagues (2012) used the distance covered in the last 30s of the test to

determine critical speed. The distance covered before the last 30s was termed the distance

covered above the critical speed (Pettitt et al., 2012). These results using a GPS during the 3

minute all out run test together with using a 2 compartment model were utilized to estimate race

performances for 800m, 1600m, and 5000m. The researchers found that a 3 minute all out run

test estimated race performance for a 1600m track or 5000m cross country race within 2 percent

of actual performance, but had greater variation (5%) when used to estimate 800m performance

(Pettitt et al., 2012). Another important point made by the authors was that the 3 minute all out run test can provide estimates of performance without performing a graded exercise test to determine a speed or $\dot{V}0_2$max (Pettitt et al., 2012).

Broxterman et al. (2013) sought to determine the accuracy of a 3 minute all out run test because, prior to their study, accuracy had been not been tested for the mode of running, only inferred from cycling. Healthy men and women from a variety of fitness levels (sedentary to highly trained) went to the laboratory eight times for testing (Broxterman et al., 2013). The researchers found that the end speed of the 3 minute all out test was not statistically different from laboratory determined critical speed and showed a nearly perfect correlation ($r = 0.92$) (Broxterman et al., 2013). Therefore, the 3 minute all out run test accurately estimates critical speed.

Distance covered at speeds above critical speed (D'), or anaerobic capacity for running, was also studied by both Pettit et al. (2012) and Broxterman et al. (Broxterman et al., 2013). Pettit et al. (2012) found that D' may be useful for determining interval training in females, but was not a good predictor of performance, especially as race distance increased. Broxterman et al. (2013) also cautioned using distance covered above end test speed from a 3 minute all out run test as D' because of having a large standard error greater than 5% ($11.9 \pm 5.0\%$). Therefore, a 3 minute all out run test has difficulty in precisely determining anaerobic capacity. However, a coach may be more interested in the total distance covered in a 3 minute all out run test and the changes that occur over the course of a season because it could suggest changes in critical speed, as well as potential changes in anaerobic capacity.

Sperlich et al. (2014) examined whether a 3 minute all out run test was able to provide a $\dot{V}O_2$max value and velocity at maximal lactate steady state similar to values found during

laboratory tests. Fifteen males, ages 20-40 years old, who had a training volume of 10+ hours and 50+ km of running per week completed the study (Sperlich et al., 2014). A portable metabolic system was used to collect respiratory data for the laboratory tests and 3 minute all out run test (Sperlich et al., 2014). Velocity at maximal lactate steady state was determined using laboratory tests and the speed in the last 30s of the 3 minute all out run test, which was what Pettit et al. (2012) used as critical speed. The researchers stated that the $\dot{V}O_2$max values from the laboratory test did not statistically differ from those found during the 3 minute all out run test, but because of a moderate effect size (effect size = 0.56) between the values, the 3 minute all out run test was not an appropriate measure of $\dot{V}O_2$max. Furthermore, the velocity at maximal lactate steady state (critical speed) in this study was statistically lower for the laboratory tests than the 3 minute all out run test and deemed an inappropriate measure of maximal lactate steady state (Sperlich et al., 2014). The authors cautioned using results from the 3 minute all out run test to prescribe training because there is a greater risk of overtraining from a sustained overload since the velocity at maximal lactate steady state was overestimated.

The research that has been completed concerning a 3 minute all out run test has provided some information regarding the efficacy of using that type of test. However, only one of those articles, Pettit et al. (2012), studied collegiate athletes. More research is needed to provide a better understanding of how coaches could use a 3 minute all out run test to assess and monitor their athletes.

Time Trials

A time trial is a fixed distance with time being measured. Time trials can vary in length and are often used to assess performance in a variety of ways for a distance running athlete (Bragada et al., 2010; Doyle & Martinez, 1998; Galbraith et al., 2014; Laursen, Francis, Abbiss,

Newton, & Nosaka, 2007; Millet et al., 2002). For example, Bragada et al. (2010) used a 3 km time trial at six testing sessions over the course of two consecutive years for middle distance runners to assess changes in performance. The authors found a decrease in performance over the course of two years and determined this finding was because the athletes were not specifically training for a 3 km race (Bragada et al., 2010). On the other hand, Galbraith et al. (2014) used time trials of 3600m, 2400m, and 1200m in order to calculate critical speed. Since there were increases in critical speed as training volume increased over the course of a year, Galbraith et al. (2014) concluded that critical speed is related to training volume.

Time trials have been shown to be more reliable than laboratory based time to exhaustion runs unless time to exhaustion tests have a very controlled setting prior to and during testing (Doyle & Martinez, 1998; Laursen et al., 2007). Laursen et al. (2007) compared 1500m and 5 km time trials to time to exhaustion tests at the average speeds measured in the time trials. The researchers found that there was more variability for the time to exhaustion tests than for the time trials (Laursen et al., 2007), suggesting that the ability of the athlete to change speeds as necessary played an important role. Doyle et al. (1998) had a very stringent 2 day control period before each testing session completed. The time trial distance was based on previous testing of a 90 min run at a constant intensity (Doyle & Martinez, 1998). The authors found that their protocol was reliable, which was due to the very controlled 2 day period prior to testing. Therefore, using a time trial seems to be the more practical, time efficient approach to monitoring athletes.

<u>Current Collegiate Distance Running</u>

What qualifies as a distance running event has been debated by coaches and administrators, especially within the realm of collegiate athletics. However, most collegiate

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distance athletes will compete in multiple events over the course of a year. For example, a

collegiate distance runner may compete in cross country running mostly 5 km race and then

compete in the 800m during indoor and outdoor track. Therefore, for the purposes of this

dissertation distance running athletes encompassed athletes who competed in events ≥ 800m on a

regular basis. There are a few differences in what races are competed between the National

Collegiate Athletic Association (NCAA) and the National Association of Intercollegiate

Athletics (NAIA). See Table 2.1 for the list of events for NCAA and NAIA. NCAA athletes and

NAIA athletes compete against each other regularly in the events that both associations sponsor.

However, having different races will influence the way a coach approaches training and

competition based on each athlete.

Collegiate athletes have many different factors that have an intangible effect on

performance. For example, the stresses of balancing a social life, a relationship, academics, and

time requirements of training can all affect performance in training and races.

Table 2.1.

List of events competed at the national meets for the NCAA and NAIA, governing bodies of collegiate athletics.

	NCAA	NAIA
Season		
Cross Country	10 km (men) / 6 km (women)	8 km (men) / 5 km (women)
Indoor Track and Field	800 m 1 mile 3 km 5 km	800 m 1 km 1 mile 3 km 5 km
Outdoor Track and Field	800 m 1500 m 3 km steeplechase 5 km 10 km	800 m 1500 m 3 km steeplechase 5 km 10 km marathon

CHAPTER 3

RELATIONSHIP BETWEEN PHYSIOLOGICAL PARAMETERS, STRENGTH PARAMETERS, COACH RANK, AND A 3 KM TIME TRIAL

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Abstract

Purpose: The purpose of this study was to examine the relationships between physiological parameters, relative strength parameters, maximal strength parameters, coach's rank, and a 3 km time trial. **Methods:** The head coach ranked the athletes from best to least prior to any athlete monitoring sessions. Twelve NCAA Division I distance running athletes (7 males, 5 females) completed three athlete monitoring testing sessions. All testing sessions were completed on separate days. Session 1 consisted of a 3 km time trial, with the whole team starting together. Session 2 consisted of a test for hydration status followed by a test for maximal oxygen consumption on a treadmill using an Astrand protocol. Data was collected by a metabolic cart and a 1 min average was used for later analysis. Session 3 consisted of a test for hydration status, body composition, vertical jumps, and isometric mid-thigh pulls. Body composition was assessed using skinfolds. A series of unweighted (0 kg PVC pipe) and weighted (20 kg bar) static and countermovement vertical jumps were measured on a force plate. Isometric mid-thigh pulls were measured while the athletes stood on a force plate in a custom designed power rack. Pearson's correlations were used to determine relationships between physiological parameters, relative strength parameters, maximum strength parameters, and a 3 km time trial. A Spearman's Rho correlation was used to determine the relationship between physiological parameters, relative strength parameters, maximum strength parameters, a 3 km time trial, and coach rank. **Results:** Maximum strength parameters indicated strong to very strong correlations with $\dot{V}O_2$max and 3 km run performance. $\dot{V}O_2$max indicated a nearly perfect correlation with 3 km run performance, while body fat % indicated a very strong negative correlation with 3 km run performance.

Conclusions: Maximum strength was an important factor in performance during a 3 km time trial. A 3 km time trial seems to be a useful, practical athlete monitoring tool for distance runners and coaches because of the strong relationships to laboratory tested variables.

1. Introduction

Distance running performance, at any level, can be limited by different physiological factors (Bassett & Howley, 2000; Billat, 2001; Powers & Howley, 2012; Saunders, Pyne, Telford, & Hawley, 2004). Those factors consist of maximal oxygen consumption ($\dot{V}O_2$max), running economy (RE), and the lactate threshold (LT). However, these factors are not often tested in a collegiate distance running population because of the time consuming nature of the tests, the monetary costs of the tests, and/or not having access to a facility with a sport science staff and necessary equipment to test.

Collegiate coaches do try to program training in such a fashion to improve $\dot{V}O_2$max, RE, and LT, but their primary concern is not how much each of those variables are changing, rather it is are the athletes improving performance. Performance in collegiate distance runners has been shown to improve with training in some studies (Tanaka et al., 1984; Tanaka et al., 1986), while in other studies performance has not improved or even decreased with training (Bragada et al., 2010; Houmard et al., 1991). These differences may be due to the different training programs with different volumes and intensities of training. One thing to note with these studies is that monitoring the athletes, with tools other than running times, did not occur in any of the studies except Bragada, et al (2010).

Bragada, et al (2010) monitored $\dot{V}O_2$max, RE, performance, velocity at $\dot{V}O_2$max (v$\dot{V}O_2$max), and velocity at 4 mmol blood lactate concentration (V4) six times over the course of two competitive seasons in 3 km athletes. The authors stated that V4 and v$\dot{V}O_2$max were the best predictors of performance for 3 km. However, because no statistically significant changes occurred in $\dot{V}O_2$max or RE in the study, those variables are less likely to predict performance (Bragada et al., 2010). Other research agrees that $\dot{V}O_2$max is not the best predictor of race

performance (Daniels, Yarbrough, & Foster, 1978; Jones, 1998). Nevertheless, coaches cannot ignore training to improve $\dot{V}O2max$, since $\dot{V}O2max$ has been shown to change with training (Daniels et al., 1978; Galbraith, Hopker, Cardinale, Cunniffe, & Passfield, 2014) and influence performance (Bassett & Howley, 2000; Powers & Howley, 2012).

Running economy, the amount of energy used to run at a given pace, has been shown to account for much of the variation in run performance (Conley & Krahenbuhl, 1979). RE can be influenced by different factors, such as strength. Increasing maximum strength has been shown to improve RE (Johnston, Quinn, Kertzer, & Vroman, 1997; Saunders et al., 2006; Storen, Helgerud, Stoa, & Hoff, 2008) and, ultimately, run performance (Harman et al., 2008; Hoffman, Kraemer, Fry, Deschenes, & Kemp, 1990; G. Millet, B. Jaouen, F. Borrani, & R. Candau, 2002; Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999; Skovgaard et al., 2014; Stone et al., 2006). Therefore, if strength has an effect on RE and performance, athletes should benefit from increasing maximum strength levels. Maximum strength can be measured via isometric mid-thigh pulls or dynamically using 1RM's, while vertical jumps can be used to assess dynamic relative strength in track and field athletes (Kraska et al., 2009; G. P. Millet, B. Jaouen, F. Borrani, & R. Candau, 2002).

Collegiate coaches often use run performances to monitor their athletes over the course of a season. There is little research on various field tests, such as a 3 km time trial, to ascertain if there are relationships to variables associated with increasing overall distance run performance. Therefore, the purpose of this study was to explore the relationships between a 3km time trial and laboratory measures ($\dot{V}O_2max$, body fat percentage, relative strength/power parameters, and maximum strength parameters) in collegiate distance runners. A secondary purpose was to examine the relationship between the coach's rank and the athlete placement on the various tests.

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2. Methods

This study was approved by the Institutional Review Board at East Tennessee State University. The head coach ranked the athletes from best to least prior to any data collection.

2.1 Athletes

Twelve NCAA Division I distance runners (7 males, 5 females) completed three athlete monitoring testing sessions in the early portion of the cross country season. All testing sessions were completed on separate days in a two week time frame. Athletes were asked not to exercise for 24 hours prior to testing. Athletes were instructed not to consume food or caffeine within three hours of testing. Athletes were allowed to consume water ad libitum.

2.2 Session 1 – 3 km time trial

Athletes performed the standard team warm-up that consisted of jogging at a self-selected pace and some dynamic stretching. Then the 3 km time trial was run on a standard flat outdoor track, with the whole team starting the time trial together.

2.3 Session 2 – Hydration, $\dot{V}O_2max$

This session consisted of a test for hydration status and maximal oxygen consumption ($\dot{V}O_2max$). Athletes were asked to provide a urine sample upon entering the laboratory. Urine was tested using a digital refractometer (PAL 10S, Atago USA, Inc) to obtain a urine specific gravity value. If the urine specific gravity was ≥ 1.020, athletes were required to drink water and retested approximately thirty minutes after the initial hydration test. Athletes with a urine specific gravity of <1.020 were classified as adequately hydrated and were allowed to continue the testing session.

Athletes completed a standardized warm-up prior to the $\dot{V}O_2$max test. The $\dot{V}O_2$max test was performed on a treadmill (Quinton Q65, Quinton Technology Inc., Seattle, WA) using the Astrand protocol (Powers & Howley, 2012). The athlete wore a heart rate monitor (Polar Elctro Inc., Lake Success, NY, USA) and head gear with a mouthpiece and nose clip. The test was terminated when the athletes reached volitional exhaustion.

Breath-by-breath data was collected using a metabolic cart (TruOne 2400, ParvoMedics, Sandy, UT). Data was later analyzed using a 1 minute average. Rating of perceived exertion (RPE) using the Borg scale (Borg, 1970) was collected in the last 15 seconds of each stage. Upon completion of the test, the athlete began walking slowly on the treadmill as soon as the facemask was removed. A maximal oxygen consumption value was determined using the following criteria for reaching $\dot{V}O_2$max: heart rate $\pm$ 10 beats per minute of age predicted max heart rate, respiratory exchange ratio (RER) > 1.1, VO_2 plateau, and/or RPE.

2.4 Session 3 – Hydration, Body Composition, Vertical Jumps and Isometric Mid-thigh Pulls

Upon arrival, athletes were asked for a urine sample to test hydration status. Athletes were adequately hydrated before continuing testing. After the hydration test, height (cm) and mass (kg) were measured twice. An average of dual measurements were used for later data analysis. Body composition (% fat) was estimated using air plethysmography (BodPod, Life Measurements Inc., Concord, CA).

Following body composition measurements, athletes completed a standardized warm-up for vertical jump and maximal strength testing (Kraska et al., 2009). The warm-up consisted of 25 jumping jacks and mid-thigh pulls (1 set of 5 with the bar only, 3 sets of 5 with 40kg and 60kg for women and men, respectively). The athletes completed static (SJ) and

countermovement (CMJ) jumps in an unweighted and two weighted conditions. Athletes

performed two warm up jumps at 50% and 75% effort before the unweighted jumps began and 1

warm up jump at 75% effort before each of the weighted jump conditions. Then athletes

completed two jumps for each condition, unweighted (0kg PVC pipe) and weighted (20kg bar)

static and countermovement jumps. All jumps were performed on a 0.91m x 0.91m force plate

(Rough Deck, Rice Lake Weighing Systems, WI) at a sampling rate of 1000 Hz. Vertical jump

data was collected and analyzed using customized LabView software (National Instruments Co.,

Austin, TX). The average jump height of two jumps at each load and condition was used for later

analysis.

For static jumps, each athlete was asked to start in a 90° knee angle, which was measured

with a manual goniometer prior to the initial warm-up jump and required to achieve before

warm-up jumps were completed. This knee angle and any countermovement was visually

assessed for each jump. Static jumps were also assessed for countermovements using the

graphical representation of the jump on LabView. If either a knee angle or a countermovement

discrepancy occurred during the static jump, the jump was deemed unsuccessful and athletes

were required to complete another jump. Two successful jumps from each condition (2-0kg SJ,

2-20kg SJ, 2-0kg CMJ, 2-20kg CMJ), for a total of 8 jumps, were used for data analysis.

Absolute fall off from unweighted to weighted jumps was used as a measure of relative strength.

An estimation of peak power was made using 0kg static jump height in Sayers-SJ equation

(Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999).

Maximum strength was measured immediately following vertical jump testing using an

isometric mid-thigh pull. All athletes were familiar with the testing position and had previously

practiced the pulling position. Athletes stood on a force plate in a custom designed power rack.

Athletes were placed in a mid-thigh pull position based on standing posture and optimal pulling position. The knee angle and bar height were recorded for each athlete. Then the athletes hands were attached to the bar using lifting straps and athletic tape to ensure grip strength and hands slipping were not limiting factors of a maximal pull.

The athlete performed two practice trials to ensure posture was correct and provide an additional warm-up. The first practice trial was performed at a perceived 50% of maximum, and the second trial was at 75% of maximum. The athlete then performed two maximum test trials, in which they were instructed to pull "as hard and as fast as possible". Approximately two minutes rest was given between the maximum test trials. Isometric force during the mid-thigh pulls was measured using a 0.91 x 0.91 force plate (Rough Deck, Rice Lake Weighing Systems, WI) at a sampling rate of 1000 Hz. Data from the isometric mid-thigh pulls was analyzed using customized LabView software (National Instruments Co., Austin, TX).

2.5 Analysis

All data were reported as the mean ± standard deviation. Pearson's correlations were used to determine the relationships between physiological parameters, relative strength/power parameters, maximum strength parameters, and a 3 km time trial. A Spearman's Rho correlation was used to determine the relationship between physiological parameters, relative strength/power parameters, maximum strength parameters, a 3 km time trial, and coach rank. Strength of the relationship was determined using the following criteria: trivial ($r<0.001$), small ($r=0.1$ to 0.2), moderate ($r=0.3$ to 0.4), strong ($r=0.5$ to 0.6), very strong ($r=0.7$ to 0.8), nearly perfect ($r=0.9$), and perfect ($r=1.0$) (Hopkins, 2000). Statistical significance criterion for these relationships was $r=0.58$, $p<0.05$. Statistics were run in SPSS (Version 22, IBM, New York, NY).

3. Results

The relationships between the variables of interest were similar for men and women, respectively. Therefore, data was combined for all analysis. Descriptive statistics of the athletes are listed in Table 3.1. Pearson correlation coefficients for relationships between relative $\dot{V}O_2max$, body fat percentage, 0kg and 20kg static and countermovement jumps, absolute fall off from 0-20kg static and countermovement jumps, and estimated peak power are listed in Table 3.2. Pearson correlation coefficients for relationships between relative $\dot{V}O_2max$, body fat percentage, isometric peak force (IPF), force at 50 ms, rate of force development (RFD), allometrically scaled isometric peak force (IPFa), and allometrically scaled force at 50 ms (a50ms) are listed in Table 3.3. Pearson correlation coefficients for relationships between 3 km time trial times, relative $\dot{V}O_2max$, body fat percentage, 0kg and 20kg static and countermovement jumps, absolute fall off from 0-20kg static and countermovement jumps, estimated peak power, isometric peak force (IPF), force at 50 ms, rate of force development (RFD), allometrically scaled isometric peak force (IPFa), and allometrically scaled force at 50 ms (a50ms) are listed in Table 3.4. Spearman's Rho correlation coefficients for relationships between coach rank, 3 km time trial times, relative $\dot{V}O_2max$, body fat percentage, 0kg and 20kg static and countermovement jumps, absolute fall off from 0-20kg static and countermovement jumps, estimated peak power, isometric peak force (IPF), force at 50 ms, rate of force development (RFD), allometrically scaled isometric peak force (IPFa), and allometrically scaled force at 50 ms (a50ms) are listed in Table 3.5.

Average SJ jump height was 24.8 ± 4.5 cm and 17.4 ± 4.4 cm for 0 kg and 20 kg conditions, respectively. Average CMJ jump height was 27.7 ± 4.9 cm and 19.1 ± 4.5 cm for 0 kg and 20 kg conditions, respectively. There were trivial to small, non-statistically significant,

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correlations between jump height for both static and countermovement jumps and Rel. $\dot{V}O_2$max, % Body Fat, and 3 km time.

Average absolute falloff in jump height from 0 kg to 20 kg SJ was 7.4 ± 1.7 cm. Average absolute falloff in jump height from 0 kg to 20 kg CMJ jumps was 8.6 ± 1.4 cm. There were small to moderate, non-statistically significant, correlations between AFO 0-20kg SJ and Rel. $\dot{V}O_2$max, % Body Fat, and 3 km time. There were trivial to small, non-statistically significant, correlations between AFO 0-20kg SJ and Rel. $\dot{V}O_2$max, Body Fat %, and 3 km time.

Average Peak Power Est. from 0kg static jumps was 2274.8 ± 489.5 W. There was a small to moderate, non-statistically significant, positive correlation between Peak Power Est. (0 kg static jump) and Rel. $\dot{V}O_2$max. There were small to moderate, non-statistically significant, negative correlations between Peak Power Est. (0 kg static jump), % Body Fat, and 3 km time.

Average isometric peak force was (IPF) 2665.9 ± 534.2 N. Average force at 50 ms (50ms) was 916.3 ± 181.9 N. Force at 50ms was reported, as opposed to 90ms and 250ms, because it indicated the strongest correlations to the variety of other variables. Average rate of force development (RFD) was 4506.5 ± 1675.3 N/s. Average allometrically scaled isometric peak force (IPFa) was 164.7 ± 24.9 N/kg$^{0.67}$. Average allometrically scaled force at 50 ms (a50ms) was 56.4 ± 7.2 N/kg$^{0.67}$. There were strong to very strong ($p < 0.05$) positive correlations between IPF, 50ms, RFD, a50ms, and Rel. $\dot{V}O_2$max. A moderate, non-statistically significant, positive correlation existed between IPFa and Rel. $\dot{V}O_2$max. Moderate to strong, non-statistically significant, negative correlations were found between IPF, 50ms, RFD, a50ms, and % Body Fat. Strong to very strong ($p < 0.05$) negative correlations were found between IPF, 50ms, RFD, a50ms, and 3 km time. A moderate, non-statistically significant, negative correlation existed between IPFa and 3 km time.

Spearman's rho correlation coefficients for relationships with coach rank are listed in Table 3.5. There were strong negative correlations ($p < 0.05$) between coach rank and Rel. V̇O2max, 50ms and a50ms. There was a very strong positive correlation ($p < 0.05$) between coach rank and 3 km time. There were small to moderate, non-statistically significant, negative correlations between coach rank and all vertical jump variables, IPF, RFD, and IPFa. There was a moderate, non-statistically significant, positive correlation between coach rank and % Body Fat.

Table 3.1. Descriptive statistics (mean ± SD, CV(%)) for the athletes (N=12)

	Mean ± SD	CV (%)
Height (cm)	171.2 ± 7.7	4.5
Body mass (kg)	62.4 ± 6.3	10.1
Percentage Body Fat	12.5 ± 7.6	60.7
Relative V̇O2max (ml/kg/min)	59.2 ± 9.6	16.2
3 km time (s)	622.2 ± 108.3	17.4

Table 3.2. Correlations between physiological parameters and relative strength/power parameters.

	0kg SJ	20kg SJ	AFO 0-20kg SJ	0kg CMJ	20kg CMJ	AFO 0-20kg CMJ	Peak Power Est.
Rel. V̇O2 max	0.14	0.01	0.36	-0.02	-0.02	-0.03	0.39
Body Fat %	-0.09	0.02	-0.28	0.08	0.07	0.07	-0.28

*Statistically significant, $p < 0.05$. Abbreviations: Rel. V̇O2max = relative V̇O2max (ml/kg/min), Body Fat % = body fat percentage (%), 0kg SJ = average jump height for 0 kg SJ (cm), 20kg SJ = average jump height for 20 kg SJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), 0kg CMJ = average jump height for 0 kg CMJ (cm), 20kg CMJ = average jump height for 20 kg CMJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), Peak Power Est = peak power (W) estimated from Sayers SJ using the 0 kg SJ

Table 3.3. Correlations between physiological parameters and maximum strength parameters.

	IPF	50ms	RFD	IPFa	a50ms
Rel. $\dot{V}O_2$ max	0.58*	0.69*	0.58*	0.45	0.71*
Body Fat %	-0.40	-0.50	-0.45	-0.32	-0.54

*Statistically significant, $p < 0.05$. Abbreviations: Rel. $\dot{V}O_2$max = relative $\dot{V}O_2$max (ml/kg/min), Body Fat % = body fat percentage (%), IPF = isometric peak force, 50ms = force at 50 milliseconds, RFD = rate of force development, IPFa = Allometrically scaled isometric peak force, a50ms = force at 50 milliseconds allometrically scaled

Table 3.4. Correlations between physiological parameters, relative strength/power parameters, maximum strength parameters, and 3 km time trial performance

	3 km time
Rel. $\dot{V}O_2$max	-0.92*
% Body Fat	0.82*
0kg SJ	-0.13
20kg SJ	-0.08
AFO 0-20kg SJ	-0.14
0kg CMJ	0.05
20kg CMJ	-0.02
AFO 0-20kg CMJ	0.24
Peak Power Est.	-0.50
IPF	-0.66*
50ms	-0.81*
RFD	-0.65*
IPFa	-0.49
a50ms	-0.82*

*Statistically significant, $p < 0.05$. Abbreviations: Rel. $\dot{V}O_2$max = relative $\dot{V}O_2$max (ml/kg/min), Body Fat % = body fat percentage (%), 0kg SJ = average jump height for 0 kg SJ (cm), 20kg SJ = average jump height for 20 kg SJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), 0kg CMJ = average jump height for 0 kg CMJ (cm), 20kg CMJ = average jump height for 20 kg CMJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), Peak Power Est = peak power (W) estimated from Sayers SJ using the 0 kg SJ, IPF = isometric peak force, 50ms = force at 50 milliseconds, RFD = rate of force development, IPFa = Allometrically scaled isometric peak force, a50ms = force at 50 milliseconds allometrically scaled

Table 3.5. Correlations between coach rank, physiological parameters, relative strength/power parameters, maximum strength parameters, and 3 km time trial performance

	Coach Rank
3 km time	0.76*
Rel. $\dot{V}O_2max$	-0.58*
% Body Fat	0.35
0kg SJ	-0.27
20kg SJ	-0.21
AFO 0-20kg SJ	-0.31
0kg CMJ	-0.29
20kg CMJ	-0.21
AFO 0-20kg CMJ	-0.17
Peak Power Est.	-0.48
IPF	-0.46
50ms	-0.60*
RFD	-0.23
IPFa	-0.26
a50ms	-0.60*

*Statistically significant, $p < 0.05$. Abbreviations: Rel. $\dot{V}O_2max$ = relative $\dot{V}O_2max$ (ml/kg/min), Body Fat % = body fat percentage (%), 0kg SJ = average jump height for 0 kg SJ (cm), 20kg SJ = average jump height for 20 kg SJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), 0kg CMJ = average jump height for 0 kg CMJ (cm), 20kg CMJ = average jump height for 20 kg CMJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), Peak Power Est = peak power (W) estimated from Sayers SJ using the 0 kg SJ, IPF = isometric peak force, 50ms = force at 50 milliseconds, RFD = rate of force development, IPFa = Allometrically scaled isometric peak force, a50ms = force at 50 milliseconds allometrically scaled

4. Discussion

Many coaches will use time trials or races of varying distances to monitor the improvements of their athletes, but do not think about the variables changing other than performance. The goal was to ascertain which variables were related and if there were any relationships between a 3 km time trial and physiological parameters, relative strength parameters, maximum strength parameters and coach's rank to determine if it is a viable resource for athlete monitoring.

Because strength has been shown to influence run performance (Harman et al., 2008; Hoffman et al., 1990; G. Millet et al., 2002; Paavolainen et al., 1999; Skovgaard et al., 2014;

Stone et al., 2006), maximum strength and dynamic relative strength (vertical jumps) parameters were measured in this study. Even though, dynamic relative strength parameters showed only trivial to small relationships with $\dot{V}O_2$max, Body Fat %, and 3 km time, relationships between maximal strength and $\dot{V}O_2$max, Body Fat %, and 3 km time were moderate to very strong. These relationships indicate that the greater the maximal strength of an athlete the higher the $\dot{V}O_2$max, the lower the Body Fat %, and the faster they ran 3 km. Thus, absolute maximal strength seems to play a larger role in performance than relative strength as measured by vertical jumps.

However, increasing maximal strength may not be the cause of an increase in $\dot{V}O_2$max in distance runners (Hurley et al., 1984). Maximal strength may, on the other hand, allow for more movement efficiency because of increases in neuromuscular function (Paavolainen et al., 1999). Strength training increases maximal strength and neuromuscular function (e.g., positive changes in cross sectional area of the muscle, increased muscle fiber recruitment, increased elastic energy storage, etc.) (Bazyler, Abbott, Bellon, Taber, & Stone, 2015; Hakkinen et al., 2003; Stone et al., 2006), which would allow distance runners to have less metabolic stress for a given running speed than weaker athletes (Bazyler et al., 2015; Stone et al., 2006).

Dynamic relative strength measured via vertical jump and absolute fall off from unweighted to weighted jumps showed trivial to small relationships with $\dot{V}O_2$max, Body Fat %, and 3 km time. This finding may be influenced by several factors: a small sample size, strength levels of the athletes were low, the athletes were not accustomed to jumping in this manner, and/or athletes did not give a maximum effort during the jumps. From years of athlete monitoring in the sport science lab at East Tennessee State University, the data for the athletes in the current study shows that these athletes are often among the weakest, similar to untrained individuals.

In regards to the 3 km time trial, strong to nearly perfect negative correlations were found with $\dot{V}O_2max$, IPF, 50ms, RFD, and a50ms. This finding indicates that the higher the $\dot{V}O_2max$, the faster the time for the 3 km time trial. Also, the stronger the athlete was, the faster the time for the 3 km time trial. Therefore, it could be assumed that if performance on the 3 km time trial increases, at least one variable affecting run performance has shown improvement. Furthermore, coaches using a 3 km time trial as a monitoring tool could assess the effectiveness of the training program they use. However, if major changes are made to the training program, those should be taken into account when comparing results from athlete monitoring.

Another interesting finding of this study was that coach rank showed strong correlations with 3 km time trial ($r = 0.76$), Rel. $\dot{V}O_2max$ ($r = -0.58$), and 50 ms ($r = -0.60$), meaning that the coach's rank had a fairly good predictive ability for those variables. This finding indicates that coaches have some ability to assess their athletes and using a practical tool like a 3 km time trial could help coaches monitor their athletes on a regular basis.

In summary, distance running coaches should incorporate resistance training into their training programs because this study has added to the evidence that maximal strength has a positive influence on run performance. Furthermore, a 3 km time trial seems to be a useful monitoring tool for distance running athletes and coaches.

4.1 Conclusions:

- Increasing maximum strength via resistance training may improve run performance.

- A 3 km time trial is a practical and useful athlete monitoring tool for distance runners

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CHAPTER 4

RELATIONSHIP BETWEEN PHYSIOLOGICAL AND STRENGTH PARAMETERS AND A
THREE MINUTE ALL OUT RUN PERFORMANCE.

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Abstract

Purpose: The purpose of this study was to examine the relationships between physiological parameters, relative strength parameters, and a three minute all out run test in collegiate distance runners. **Methods:** Fifteen NAIA collegiate distance runners (9 females, 6 males) completed three athlete monitoring testing sessions. Session 1 consisted of a test for hydration status and maximal oxygen consumption ($\dot{V}O_2$max). $\dot{V}O_2$max testing was done on a treadmill using a modified Astrand protocol. Respiratory data was collected using a metabolic cart and a 15 s average was used for later analysis. Session 2 consisted of a test for hydration status and a 3 minute all out run test. The 3 minute all out run test was run individually. Data for the 3 minute all out run was collected using a GPS unit (sampling rate 10 Hz) worn on the back of a chest harness. Distance covered in the last 30 s was used to calculate critical speed. Session 3 consisted of a test for hydration, body composition, and vertical jumps. Body composition was assessed using skinfolds. A series of unweighted (0 kg PVC pipe) and weighted (20 kg bar) static and countermovement jumps were completed on a switch mat. Pearson's correlations were used to determine the relationships between physiological parameters, relative strength parameters, and a 3 minute all out run test. **Results:** Vertical jump height showed very strong correlations with $\dot{V}O_2$max, total distance covered, and critical speed. Vertical jump height showed a very strong negative correlation with body fat %. $\dot{V}O_2$max indicated nearly perfect correlations with total distance covered and critical speed. Body fat % indicated very strong negative correlations with total distance covered and critical speed. **Conclusions:** Relative strength seemed to play a role in performance during a 3 minute all out test. A 3 minute all out run test seems to be a useful, practical athlete monitoring tool for distance runners and coaches because of the very strong relationships to laboratory tested variables.

1. **Introduction**

Collegiate distance running success depends upon several factors. Maximal oxygen consumption ($\dot{V}O_2max$), running economy, and lactate threshold have been identified as factors that affect running performance (Bassett & Howley, 2000). Collegiate distance running coaches attempt to manipulate and improve these factors with training. Monitoring the athletes over the course of a training cycle is also an important concept. However, due to perceived time and monetary costs of testing, few coaches monitor these factors.

Maximal oxygen consumption is defined as the maximum amount of oxygen that can be consumed in one minute (Bassett & Howley, 2000; Powers & Howley, 2012). $\dot{V}O_2max$ values have been shown to change with changes in training (J. T. Daniels, Yarbrough, & Foster, 1978; Galbraith, Hopker, Cardinale, Cunniffe, & Passfield, 2014). Distance training studies for runners have often based training off a percentage of $\dot{V}O_2max$ and/or percentage of maximum heart rate, obtained during a $\dot{V}O_2max$ test (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999; Harman et al., 2008; Kraemer et al., 2004).

Many coaches have used only a time trial or race performance to assess the abilities of their athletes and/or to assign a VDOT (a shortened term for estimated $\dot{V}O_2max$) value and ultimately training paces. Jack Daniels, a renowned running coach and researcher in distance running, states in his book (J. Daniels, 2013) that there are moderate to strong correlations between race performance at varying distances and pace at anaerobic threshold. From these correlations, an athlete can be assigned a VDOT, or estimated $\dot{V}O_2max$, value from which training paces can be assigned according to charts in Daniels' book (2013).

Dobson, et al (2011) has shown that the predicted pace at anaerobic threshold from Daniels' chart (2007) was an accurate estimate of lab tested anaerobic threshold pace, meaning

VDOT scores would be accurate. However, research has shown that maximal oxygen consumption values are not the best predictors of race performance (J. T. Daniels et al., 1978; Jones, 1998).

Running economy has been shown to account for a large percentage of the variation in run performance (Conley & Krahenbuhl, 1979). For example, if two runners maintained a constant speed, the athlete with a lower oxygen consumption value would have a better running economy (Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999). Several factors have been shown to influence running economy. For example, strength has been shown to markedly influence running economy (R. E. Johnston, Quinn, Kertzer, & Vroman, 1997; Saunders et al., 2006; Storen, Helgerud, Stoa, & Hoff, 2008) and, ultimately, improve run performance (Harman et al., 2008; Hoffman, Kraemer, Fry, Deschenes, & Kemp, 1990; Millet, Jaouen, Borrani, & Candau, 2002; Paavolainen et al., 1999; Skovgaard et al., 2014; Stone et al., 2006). Maximum strength tests can be fatiguing and time costly. However, jump testing is relatively non-fatiguing and requires less time. Furthermore, vertical jump testing has previously been used to assess relative strength and power in track and field and cross country athletes (Cole, Woodruff, Horn, & Mahon, 2006; Kraska et al., 2009).

As stated above, lactate threshold has been identified as a factor in run performance (Bassett & Howley, 2000; Farrell, Wilmore, Coyle, Billing, & Costill, 1993) and can change with training (Bassett & Howley, 2000; J. Daniels, 1974; Galbraith et al., 2014; Joyner, 1993). Lactate threshold occurs at the work rate at which the concentration of blood lactate begins to rise exponentially (Brooks, Fahey, & White, 2005; McGehee, Tanner, & Houmard, 2005; Stone, Stone, & Sands, 2007). However, lactate threshold is not often measured, but estimated, in distance runners due to time and monetary costs of testing. Furthermore, maximal lactate steady

state may be of more interest in distance running. The velocity associated with maximal lactate steady state has been used to prescribe training for endurance athletes (Billat, Sirvent, Lepretre, & Koralsztein, 2004; Philp, Macdonald, Carter, Watt, & Pringle, 2008).

Additionally, critical speed has been shown to have a strong correlation with the velocity at maximal lactate steady state during an intermittent protocol (de Lucas, Dittrich, Junior, de Souza, & Guglielmo, 2012). de Lucas, et al (2012) stated that their findings mean that critical speed can be used to prescribe paces for interval training. Recently, a three minute all out run test has been used to determine critical speed in runners (Pettitt, Jamnick, & Clark, 2012). Furthermore, the three minute all out run test was found to be an accurate method to determine critical speed in runners (Broxterman, Ade, Poole, Harms, & Barstow, 2013). However, there has not been a study to date that explores the relationship of the three minute all-out run test compared to other laboratory based tests for runners.

Therefore, the purpose of this study was to examine the relationships between physiological and strength parameters (laboratory measures) and a three minute all out run performance in collegiate distance runners.

2. Methods

All athletes read and signed informed consent documents concerning the long term athlete monitoring program that were approved by the Institutional Review Boards at East Tennessee State University and Milligan College. Athlete monitoring occurred at the beginning of the outdoor track and field season.

2.1 Athletes

Fifteen (9 women, 6 men) NAIA collegiate distance runners completed three testing sessions for athlete monitoring. The athletes completed testing sessions in this order: $\dot{V}O_2$ max, 3 minute all out run, and body composition and vertical jump testing. All testing sessions had a test of hydration status at the beginning because dehydration can negatively affect performance (Barr, 1999; Montain et al., 1998; Walsh, Noakes, Hawley, & Dennis, 1994). Hydration testing consisted of athletes providing a urine sample and several drops of urine were tested using a digital refractometer (PAL 10S, Atago USA, Inc) to obtain a urine specific gravity value. If the urine specific gravity was ≥ 1.020, athletes were required to drink water and retested approximately thirty minutes after the initial test. Athletes with a urine specific gravity of <1.020 were classified as adequately hydrated and were allowed to continue the testing session. All three testing sessions were completed within a two week time frame, on separate days, with at least 24 hours of no exercise prior to each testing session. Athletes were asked not to consume caffeine or food within the three hours prior to testing. Water was consumed ad libitum.

2.2 Session 1 – Hydration, $\dot{V}O_2$max

This session consisted of a hydration test and test for maximal oxygen consumption ($\dot{V}O_2$max). Upon arrival athletes were asked for a urine sample to test hydration status. Each athlete had to reach an adequate estimate of hydration before being allowed to continue with testing. If the athlete was adequately hydrated, the athlete was asked to complete a 10 minute jogging warm-up at a self-selected pace.

Then, the $\dot{V}O_2$max test was performed on a treadmill (TM55 Quinton Q-stress system, Cardiac Science, Hannover, Germany).The athlete donned a heart rate monitor (Polar Team[2],

Polar Elctro Inc., Lake Success, NY, USA) and head gear with a mouthpiece and nose clip for

the $\dot{V}O_2$max test. After these devices were adjusted for fit and comfort, the athlete walked at 1.8

m/s and 0% grade for 5 minutes as a warm-up and to ensure equipment was working properly. A

modified Astrand testing protocol was chosen based on the population of athletes being tested. In

our laboratory, the test-retest reliability of this modified Astrand protocol has been ICC = 0.99.

The speed of the treadmill increased after the warm-up (up to 3.1 m/s for females and 3.8 m/s for

males). The speed remained the same throughout the duration of the test. However, grade

increased by 2% every three minutes. Three minute stages were used because it is possible to

reach a steady state for a constant workload within three minutes (Wilmore & Costill, 2004). The

test was terminated when the athlete reached volitional exhaustion. Table 1 is an example of the

speed and grade relationship during the test.

Table 4.1. Modified Astrand protocol for $\dot{V}O_2$max testing.		
Stage	**Speed (Females/Males)**	**Grade**
1	3.1 m/s / 3.8 m/s	0%
2	3.1 m/s / 3.8 m/s	2%
3	3.1 m/s / 3.8 m/s	4%
4	3.1 m/s / 3.8 m/s	6%
5	3.1 m/s / 3.8 m/s	8%
6	3.1 m/s / 3.8 m/s	10%

Breath-by-breath data was collected and averaged every 15 seconds using a metabolic

cart (TruOne 2400, ParvoMedics, Sandy, UT). Rating of perceived exertion using the Borg scale

(Borg, 1970) was collected in the last 15 seconds of each stage. Upon completion of the $\dot{V}O_2$max

test, the athlete began walking on the treadmill at 1.1 m/s and 0% grade as soon as the facemask

was removed. A finger-tip blood sample was taken 3 minutes after completion of the $\dot{V}O_2$max

test (Bosquet, Duchene, Lecot, Dupont, & Leger, 2006; Powers & Howley, 2012). A handheld

blood lactate meter (Lactate Plus, Nova Biomedical Corporation, Waltham, MA) was used to assess blood lactate concentration as a criteria for reaching maximum oxygen consumption. A maximum oxygen consumption value was determined using the following criteria for reaching VO_2max: Heart rate (HR) $\pm$ 10 beats of age predicted max HR, respiratory exchange ratio (RER) > 1.1, VO_2 plateau, RPE, and/or 3 minute post blood lactate > 8 mmol/L (Bosquet et al., 2006; Morrow, Jackson, Disch, & Mood, 2011; Powers & Howley, 2012).

2.3 Session 2 – Hydration, 3 minute all out run

The 3 minute all out run was tested individually on a standard flat outdoor track (Broxterman et al., 2013; Pettitt et al., 2012) on a partly sunny day with a slight breeze. Upon arrival, athletes were asked for a urine sample to test hydration status. Athletes were adequately hydrated before continuing with testing. After hydration testing, athletes put on a chest harness and GPS unit (10 Hz, MiniMaxS4, Catapult Innovations, Scoresby, Australia) to wear during the warm-up and testing. Each athlete performed the warm-up and test individually, so there was no racing/pacing with other individuals. Athletes performed a standardized warm-up consisting of jogging at a self-selected pace interspersed with dynamic stretching movements/drills. The warm up took approximately 30 minutes. For the all-out test, athletes were asked to give your best effort for the entirety of the test, which will last approximately three minutes. They were instructed to build into a speed they could maintain for three minutes (Pettitt et al., 2012). Athletes were not given any time checks during the run. In an effort to ensure enough data was collected by the GPS, the test lasted three minutes and five seconds (Pettitt et al., 2012).

The total distance covered during the three minutes and critical speed, calculated using the distance in the last thirty seconds (Pettitt et al., 2012), were used as the outcome measures of

performance. Total distance covered was used as a performance measure instead of the distance covered at speeds above critical speed (*D'*) because *D'* has been found to unreliable (Broxterman et al., 2013) and coaches will be more concerned with total distance covered in a given period of time. Both, total distance and critical speed, were found by selecting the three minutes of the test from the GPS data output. The GPS used is this study has been shown to be reliable and accurate for measuring distance at various speeds, ICC ≥ 0.88 (R. J. Johnston, Watsford, Kelly, Pine, & Spurrs, 2014).

2.4 Session 3 – Hydration, Body Composition, Vertical Jumps

Athletes were asked to give a urine sample to test hydration status after arriving. Athletes were adequately hydrated before continuing. After the hydration tests, height, mass, and skinfolds were measured to assess body composition. Height (cm) was measured twice using a digital statiometer. Mass (kg) was measured twice using a digital scale. Lange skinfold calipers (Beta Technology Inc., Cambridge, MA, USA) were used to measure skinfolds twice at each of the 7 sites (tricep, subscapular, chest, midaxillary, suprailiac, abdomen, and thigh) following ACSM guidelines (ACSM, 2010). An average of the dual measurements was used for later data analysis.

Following the body composition measures, athletes were guided through a standardized warm-up for vertical jump testing (Kraska et al., 2009). The warm-up consisted of 25 jumping jacks and mid-thigh pulls (1 set of 5 with the bar only, 3 sets of 5 with 30kg and 50kg for women and men, respectively). The athletes completed static (SJ) and countermovement (CMJ) jumps in an unweighted and two weighted conditions. Athletes were asked to perform two warm up jumps at 50% and 75% effort before the unweighted jumps begin and 1 warm up jump at 75% effort

before each of the weighted jump conditions. Then, athletes completed two jumps for each condition, unweighted (0kg PVC pipe) and weighted (20kg bar) static and countermovement jumps, immediately following the warm-up on a switch mat (Just Jump!, Probotics Inc., Hunstville, AL, USA).

For static jumps, each athlete was asked to start in a 90° knee angle, which was measured prior to the initial warm-up jump and required to achieve before warm-up jumps were completed. This knee angle and any countermovement was visually assessed for each jump. If either a knee angle or a countermovement discrepancy occurred during the static jump, the jump was deemed unsuccessful and athletes were required to complete another jump. Two successful jumps from each condition (2-0kg SJ, 2-20kg SJ, 2-0kg CMJ, 2-20kg CMJ), for a total of 8 jumps, were used for data analysis. Absolute fall off from unweighted to weighted jumps was used as a measure of relative strength. An estimation of peak power was made using 0kg static jump height in Sayers-SJ equation (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999).

2.5 Analysis

All data were reported as the mean ± standard deviation. Pearson's correlations were used to determine the relationships between physiological parameters, strength/power parameters and a 3 minute all-out run test. Strength of the relationship was determined using the following criteria: trivial ($r<0.001$), small ($r=0.1$ to 0.2), moderate ($r=0.3$ to 0.4), strong ($r=0.5$ to 0.6), very strong ($r=0.7$ to 0.8), nearly perfect ($r=0.9$), and perfect ($r=1.0$) (Hopkins, 2000). Statistical significance criterion for these relationships was $r=0.52$, $p<0.05$. Statistics were run in SPSS (Version 22, IBM, New York, NY).

3. Results

The results for men and women followed similar trends for the relationships of interest; therefore, data was combined for all analysis. Descriptive statistics of the athletes are listed in Table 2. Pearson correlation coefficients for relationships between relative $\dot{V}O_2max$, body fat percentage, 0kg and 20kg static and countermovement jumps, absolute fall off from 0-20kg static and countermovement jumps, and estimated peak power are listed in Table 3. Pearson correlation coefficients for relationships between three minute all-out run performance measures (critical speed and total distance covered), relative $\dot{V}O_2max$, body fat percentage, 0kg and 20kg static and countermovement jumps, absolute fall off from 0-20kg static and countermovement jumps, and estimated peak power are listed in Table 4.

Average SJ jump height was 35.6 ± 6.0 cm and 25.3 ± 5.0 cm for 0 kg and 20 kg conditions, respectively. Average CMJ jump height was 38.4 ± 6.9 cm and 27.2 ± 6.2 cm for 0 kg and 20 kg conditions, respectively. There were very strong positive correlations ($p \leq 0.05$) between jump height for both static and countermovement jumps and Rel. $\dot{V}O_2max$, Total Dist., and Critical Speed. There were very strong negative correlations ($p \leq 0.05$) between static jump height and Body Fat %.

Average absolute falloff in jump height from 0 kg to 20 kg SJ was 10.3 ± 2.4 cm. Average absolute falloff in jump height from 0 kg to 20 kg CMJ jumps was 11.1 ± 2.1 cm. There were moderate to strong, but not statistically different, correlations between AFO 0-20 kg for both static and countermovement jumps and Rel. $\dot{V}O_2max$, Total Dist., and Critical Speed. However, there was a strong positive correlation ($p \leq 0.05$) between AFO 0-20 kg SJ and Body Fat %.

Average Peak Power Est. using 0 kg static jump was 2927.1 ± 645.5 W. There were very strong positive ($p \leq 0.05$) correlations between Peak Power Est. (Sayers - 0 kg SJ) and Rel. $\dot{V}O_2$max, Total Dist., and Critical Speed. There was a very strong negative correlation ($p \leq 0.05$) between Peak Power Est. (Sayers - 0 kg SJ) and Body Fat %.

Table 4.2. Descriptive statistics (mean $\pm$ SD, CV(%)) for the athletes (N=15)

	Mean $\pm$ SD	CV (%)
Age (yrs)	19.9 ± 1.0	4.8
Height (cm)	172.3 ± 9.0	5.2
Body mass (kg)	62.3 ± 7.8	12.5
Percentage Body Fat	17.4 ± 7.9	45.2
Relative $\dot{V}O_2$max (ml/kg/min)	62.4 ± 8.8	14.1
Total Dist. (m)	938.1 ± 92.4	9.8
Critical Speed (m/s)	5.03 ± 0.5	9.5

Table 4.3. Correlations between physiological parameters and relative strength/power parameters.

	0kg SJ	20kg SJ	AFO 0-20kg SJ	0kg CMJ	20kg CMJ	AFO 0-20kg CMJ	Peak Power Est. (0kg SJ)
Rel. $\dot{V}O_2$ max	0.86*	0.79*	0.51	0.80*	0.76*	0.40	0.75*
Body Fat %	-0.79*	-0.71*	-0.52*	-0.74*	-0.72*	-0.31	-0.72*

*Statistically significant, $p < 0.05$. Abbreviations: Rel $\dot{V}O_2$max = relative $\dot{V}O_2$max (ml/kg/min), Body Fat % = body fat percentage (%), 0kg SJ = average jump height for 0 kg SJ (cm), 20kg SJ = average jump height for 20 kg SJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), 0kg CMJ = average jump height for 0 kg CMJ (cm), 20kg CMJ = average jump height for 20 kg CMJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), Peak Power Est = peak power (W) estimated from Sayers SJ using the 0 kg SJ

Table 4.4. Correlations between three minute all-out run performance measures and physiological and relative strength/power measures.

	Rel. $\dot{V}O_2$ max	Body Fat %	0kg SJ	20kg SJ	AFO 0-20kg SJ	0kg CMJ	20kg CMJ	AFO 0-20kg CMJ	Peak Power Est. (0kg SJ)
Total Dist. (m)	0.90*	-0.90*	0.85*	0.77*	0.51	0.78*	0.73*	0.38	0.72*
CS (m/s)	0.91*	-0.86*	0.85*	0.77*	0.48	0.75*	0.71*	0.34	0.78*

*Statistically significant, $p < 0.05$. Abbreviations: Total Dist = total distance covered in the 3 minute all-out run (m), CS = critical speed (m/s), Rel $\dot{V}O_2$max = relative $\dot{V}O_2$max (ml/kg/min), Body Fat % = body fat percentage (%), 0kg SJ = average jump height for 0 kg SJ (cm), 20kg SJ = average jump height for 20 kg SJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), 0kg CMJ = average jump height for 0 kg CMJ (cm), 20kg CMJ = average jump height for 20 kg CMJ (cm), AFO 0-20kg SJ = absolute falloff in jump height from 0-20 kg SJ (cm), Peak Power Est = peak power (W) estimated from Sayers SJ using the 0 kg SJ

4. Discussion

The current study sought to provide insight on what relationships, if any, existed between physiological parameters, relative strength parameters (from vertical jumps), power parameters, and performance measures from a three minute all-out run in an effort to find another field testing tool distance running coaches can use to monitor their athletes. By monitoring athletes on a consistent basis, assessments can be made about the degree of athlete adaptation to the training stimulus provided.

Jump height and absolute fall off in jump height between weighted and unweighted jumps were used as measures of relative strength in this study because: 1.) There are strong relationships between maximum strength, jump height, and fall off. and 2.) stronger athletes have been shown to jump higher and have less of a decrease in jump height under weighted conditions (Kraska et al., 2009). The findings of the current study showed that there was a very strong correlation between jump height and Rel $\dot{V}O_s$max. However, this does not necessarily mean that

increasing strength levels increases $\dot{V}O_2$max values directly among endurance athletes. Research has shown that this is not always the case (Hurley et al., 1984). Additional findings of the current study showed that there were very strong correlations between jump height and Total Dist. and CS. This suggested that strength played an important role in run performance for these athletes.

These relationships may be due to increased neuromuscular function and the ability to move more efficiently allowing a better performance (Paavolainen et al., 1999). Neuromuscular function can be enhanced via strength training (e.g., positive changes in cross sectional area of the muscle, increased muscle fiber recruitment, increased elastic energy storage, etc.) (Bazyler, Abbott, Bellon, Taber, & Stone, 2015; Stone et al., 2007). Therefore, stronger athletes would have less metabolic stress for a given running speed and can achieve higher intensities of exercise, than weaker athletes (Bazyler et al., 2015; Stone et al., 2006). Indeed, previous research has shown that stronger athletes jump higher (Kraska et al., 2009) and have improved running economy (R. E. Johnston et al., 1997; Saunders et al., 2006; Storen et al., 2008).

Collegiate cross country/track and field distance coaches often agree that strength is important for running performance but do not often define what they mean by strength. Discussions with collegiate coaches indicate the term strength can be used for anything from maximum strength level to relative strength level to the ability to maintain pace in a tough race. Even though, running performance has been shown to improve with strength training (Harman et al., 2008; Hoffman et al., 1990; Millet et al., 2002; Paavolainen et al., 1999; Skovgaard et al., 2014; Stone et al., 2006), many coaches do not allow some/all/few of their athletes to strength train because of fears of "bulking up" or injury from lifting weights. Consequently, many distance coaches would prefer that the athletes get stronger by only running; a practice that produces little strength gain.

Body fat %, Relative $\dot{V}O_2$max, and Jump height were strongly correlated with the three minute all-out run performance measures. Furthermore, statistically significant very strong to nearly perfect positive relationships existed for three minute all-out run performance measures (critical speed and total distance covered) and relative $\dot{V}O_2$max and jump height (SJ and CMJ). Statistically significant very strong to nearly perfect negative relationships existed for three minute all-out performance measures and body fat percentage. These relationships indicate that better performance in the three minute all-out run corresponds to a higher relative $\dot{V}O_2$max, lower percent body fat, and higher jump height. In theory, then, the results of the three minute all-out run test give a broad picture of the athlete with indirect measure/assumptions of the factors affecting run performance as stated by (Bassett & Howley, 2000). If as the season progressed, the athlete continued to perform better in the three minute all-out run test, then a coach cold assume that the training program was successful. However, caution should be used to interpret the results of the three minute all-out run test because there has been no research to date examining the occurrence of a learning effect for completing a three minute all-out run test.

A coach would be able to use a three minute all out run test in two ways: to potentially assign interval training paces (Morton & Billat, 2004; Pettitt et al., 2012) and to assess if the athletes were progressing as expected. For example, coaches could monitor changes in critical speed measured in the 3 minute all out run test to examine if training has produced the desired or expected result up to the point. Vertical jumps could also be used as a measure of relative strength for athlete monitoring.

Vertical jumps and a three minute all out run could be tested at the beginning of a training cycle/semester to establish the current training status and use critical speed determined from the test to prescribe interval training paces. Coaches already often use training paces based

of a time trial performance where a VDOT (estimated $\dot{V}O_2max$) value is assigned. However, there needs to be research on the differences of using a percentage of $\dot{V}O_2max$ and using critical speed (CS) to calculate interval training paces for running.

In summary, a three minute all-out run test is a practical field testing method to assess and monitor distance running athletes. Also, strength seems to be an important component in run performance of collegiate distance runners.

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CHAPTER 5

SUMMARY AND FUTURE RESEARCH

The purpose of this study was to examine the relationships between field tests and laboratory tests in an effort to provide insight for athlete monitoring tools for collegiate distance runners. Both studies within this dissertation found that strength seems to be an important factor in performance. Study 1 found that maximum strength was strongly correlated with 3 km run performance, whereas relative strength indicates trivial to small correlations. Study 2, on the other hand, found that relative strength was very strongly correlated with 3 minute all out performance measures. However, there was not a measure of maximum strength in study 2. These differences in which strength parameter correlates best with performance between study 1 and study 2 could be due to difference in the length of the performance test, differences in sample population.

Study 1 found that a 3 km time trial performance showed strong correlations with laboratory tests, suggesting a 3km time trial is practical tool that can be used for monitoring. Study 2 also found that measures from a 3 minute all out run test strongly correlated with laboratory measures, suggesting that it is another practical tool for athlete monitoring. Even though both are practical monitoring tools for distance running coaches, coaches should consider which one could be the most beneficial and incorporated most easily into their annual training plan. Coaches should also understand that there may be advantages to using both type of monitoring tools at specific points in the training year, but also understand that results from a 3 km time trial and a 3 minute all out run test cannot be compared, as no research has investigated if relationship exists between them.

Therefore, future research should include examining the relationship between a 3 km time trial and 3 minute all out run test to elucidate if one is superior to the other for athlete monitoring. Also, future research should investigate the effects of starting a 3 km time trial or 3 minute all out run test as a team versus starting individually. Further study is needed on a 3 minute all out run test over the course of time to investigate if changes in performance during the test correlate to changes in training volume and intensity. Finally, more research is needed on the relationship between maximum strength and performance in a 3 minute all out run test.

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APPENDICES

Appendix A: ETSU Institutional Review Board Approval – 3 km Time Trial

EAST TENNESSEE STATE UNIVERSITY

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

IRB APPROVAL – Initial Expedited Review

March 16, 2015

Jana Hollins

Re: Relationship between physiological parameters and a 3,000 m time trial performance
IRB#: c0315.1sw
ORSPA #: n/a

The following items were reviewed and approved by an expedited process:
- xform New Protocol Submission; CV

On **March 15, 2015**, a final approval was granted for a period not to exceed 12 months and will expire on **March 14, 2016**. The expedited approval of the study will be reported to the convened board on the next agenda.

This study has been granted a **Waiver or Alteration of Informed Consent** under category 45 CFR 46.116(d)(1-4). Those determinations are as follows: (1) research involves no more than minimal risk to the participants as it involves retrospective data analysis only; (2) the waiver or alteration will not adversely affect the rights and welfare of the subjects as data are already collected for monitoring purposes; (3) the research could not practicably be carried out without the waiver or alteration as data was collected several years ago and participants cannot practicably be contacted for consent and (4) providing participants additional pertinent information after participation is not appropriate.

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

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

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10

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working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

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

EAST TENNESSEE STATE
UNIVERSITY

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

IRB APPROVAL – Initial Expedited Review

March 16, 2015

Jana Hollins

Re: Relationship between physiological and strength parameters and a 3 minute all-out run performance
IRB#: c0115.12s
ORSPA #: n/a

The following items were reviewed and approved by an expedited process:
- xform New Protocol Submission; External Site Approval; Informed Consent Document (version 2/13/2015, stamped approved 2/28/2015); Data Sheets; Ranking Form; CV

On **February 28, 2015**, a final approval was granted for a period not to exceed 12 months and will expire on **February 27, 2016**. The expedited approval of the study will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document (version 2/13/2015, stamped approved 2/28/2015)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

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

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

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a

Accredited Since December 2005

case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 (www.etsu.edu/irb). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

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

Date: 1.05.15

From: The Institutional Review Board (IRB) at Milligan College

Re: Relationship between physiological and strength parameters and a 3 minute all-out run performance

Submission type: Initial Submission

Dear Jana Hollins,

On behalf of the Milligan College Institutional Review Board (IRB), we are writing to inform you that your study 'Relationship between physiological and strength parameters and a 3 minute all-out run performance,' has been approved as expedited. This approval also indicates that you have fulfilled the IRB requirements for Milligan College.

All research must be conducted in accordance with this approved submission, meaning that you will follow the research plan you have outlined here, use approved materials, and follow college policies.

Take special note of the following important aspects of your approval:

- Any changes made to your study require approval from the IRB Committee before they can be implemented as part of your study. Contact the IRB Committee at **IRB@milligan.edu** with your questions and/or proposed modifications.

- If there are any unanticipated problems or complaints from participants during your data collection, you must notify the Milligan College IRB Office within 24 hours of the data collection problem or complaint.

The Milligan College IRB Committee is pleased to congratulate you on the approval of your research proposal. Best wishes as you conduct your research! If you have any questions about your IRB Approval, please contact the IRB Office and copy your faculty advisor if appropriate on the communication.

Regards,
The IRB Committee

Milligan College, Tennessee 37682 • (423) 461-8700 • www.milligan.edu
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Appendix D: Informed Consent Document

Principle Investigator: Jana Hollins
Title of project: Relationship between physiological parameters and a 3 minute all out run performance

SUBJECT CONSENT FORM FOR PARTICIPATION OF HUMAN SUBJECTS IN RESEARCH

Project Title: Relationship between physiological and strength parameters and a 3 minute all-out run performance

Primary Investigator: Jana Hollins, MS, Department of Exercise and Sport Sciences
hollinsj@goldmail.etsu.edu

Phone: 423-439-4655 (Sport Science Lab; Minidome E113)

Introduction: This is a consent form that describes subject requirements for a research project. Please read this document carefully and decide if you wish to participate.

Purpose: to investigate the relationships between laboratory measures and run performance (field test).

More specifically, the purpose(s) of this study are
- to determine the relationship between physiological parameters ($\dot{V}O_2$max, heart rate, body composition, etc) and a 3 minute all out run performance (critical speed and total distance covered)
- to determine the relationship between estimated relative strength from vertical jumps (percent dropoff from weighted to unweighted jumps) and physiological parameters
- to determine the relationship between estimated relative strength from vertical jumps and a 3 minute all out run performance
- to determine the relationship between physiological parameters, estimated relative strength, and coaches' perceptions

The results of this study may be published in peer-reviewed journals or discussed in presentations at professional conferences.

Duration: This study will use athlete monitoring data that is currently being collected during the 2015 Spring semester.

Procedures:
If you agree to participate in this research, researchers will use your data from the current athlete monitoring session. The data will be retrieved from the athlete monitoring database. The data that will be used will be results from the current athlete monitoring tests: coaches ranking, hydration, body composition, vertical jumps, VO2max, and a 3 min all out run performance.

Possible risks/discomforts:
The only potential risk from participating is loss of confidentiality. If, for any reason, you do not wish to continue in the study, you may withdraw your data at any time.

Possible benefits:
There is no direct benefit to you in this study. The results of this study may benefit future distance runners and you future performance if you continue to compete by helping establish better training and monitoring methods.

APPROVED
By the ETSU IRB

FEB 2 8 2015
By _____
Chair IRB Coordinator

DOCUMENT VERSION EXPIRES

FEB 2 7 2016

ETSU IRB

Ver. 2/13/15   Page 1   Subject Initials_____

Principle Investigator: Jana Hollins
Title of project: Relationship between physiological parameters and a 3 minute all out run performance

Confidentiality:
Every effort will be made to ensure confidentiality of your data. A copy of the records from this study will be stored in the ETSU Sport Science Lab (MiniDome 113) for at least 5 years upon completion of this research. Data retrieved will only be accessible to study staff. The results of this study may be published and/or presented at conferences without naming you as a subject. Your rights and privacy will be maintained. However, the following persons/bodies will have access to study records: the Secretary of the Department of Health and Human Services, the ETSU Institutional Review Board, and personnel particular to this research project within the Department of Exercise and Sport Sciences. Your records will not be revealed unless required by law, or as noted above.

Financial costs: There are no financial costs to you, and no compensation for your participation.

Voluntary Participation:
Participation in this study requires the use of your current athlete monitoring data for additional analysis. There are no alternative procedures. Participation is voluntary. There are no penalties for not participating in this study; it does not affect your involvement with athlete monitoring. You are free to withdraw from the study at any time without explanation. Your withdrawal will be respected, and will not result in any loss of benefits to which you are otherwise entitled.

Contact for Questions:
You may contact any of the following persons for questions, problems, or medical issues related to this study at any time. You may contact Jana Hollins at 931-581-6707, Dr. Mike Ramsey at 423-439-4375, or Dr. Michael Stone at 423-439-5796. If you have any questions about your rights as a research subject, you may contact the Chairman of the ETSU Institutional Review Board at 423-439-6054, the ETSU Institutional Review Board Coordinator at 423-439-6055 or 423-439-6002, or the Milligan College Institutional Review Board Chair at 423-975-8011. If you have any questions or concerns about the research and want to talk to someone independent of the research team or you can't reach the study staff, you may call an IRB coordinator at 423-439-6055 or 423-439-6002.

Having read the above and had the opportunity to ask any questions, please indicate with your signature below and with your initials on the previous pages that you have read and consent to participate in this research study, and that you are at least 18 years of age. You will receive a copy of this informed consent form after signing the form.

_____
Participant's Name (please print)   Date

_____
Participant's Signature   Date

_____
Primary Investigator's Signature   Date

Ver. 2/13/15   Page 2   Subject Initials_____

JANA HOLLINS

Education:	B.S. Exercise Science: Strength and Conditioning, Appalachian State University, Boone, NC 2010
	M.S. Health and Human Development: Exercise Physiology, Montana State University, Bozeman, MT 2012
	Ph.D. Sport Physiology and Performance, East Tennessee State University, Johnson City, TN 2015
Professional Experience:	Student Assistant Strength Coach, Appalachian State University, Boone, NC, 2009
	Movement Science/Human Performance Laboratory Research Assistant, Montana State University, Bozeman, MT, 2010-2012
	Volunteer Assistant Coach – Track and Field, Montana State University, Bozeman, MT, 2011-2012
	Graduate Teaching Assistant, Montana State University, Bozeman, MT 2011-2012
	Assistant Coach – Cross Country/Track and Field, Milligan College, Milligan College, TN, 2012-2015
	Summer Intern, Zap Fitness, Lenoir, NC 2014
	Doctoral Fellow, East Tennessee State University, Johnson City, TN 2013-2015
Publications:	Higginson, B.K., Mills, K.L., Pribanic, K.A., Hollins, J.E., and Heil, D.P. "A biomechanical comparison of three backpack frames during treadmill walking." American Society of Biomechanics annual meeting 2012. Abstract accepted 2012.
	Hollins, J.E., Reinking, B.W., Pribanic, K.A., and Heil, D.P., FACSM. "Physiological and perceptual effects of backpack chest straps while wearing an armored vest." Northwest chapter American College of Sports Medicine annual meeting 2012. Abstract accepted (slide presentation) February 2012.

Hollins, J.E., Reinking, B.W., Pribanic, K.A., and Heil, D.P.,
FACSM. "Influence of backpack chest straps on heavy load
carriage while wearing an armored vest." American
College of Sports Medicine annual meeting 2013. Abstract
accepted February 2013.

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and Stone, M.H. "The Effect of a competitive season on the
explosive performance characteristics of collegiate male
soccer players." 9th annual Coaches College. Johnson City,
TN. Dec 2014.

Gleason, B.H., Hollins, J.E., Santana, H.A.P., Deweese, B.H., and
Stone, M.H. (2014). Performance training guidelines for
the 1.5 and 2-mile runs. *Journal of Trainology* 3(1).
http://trainology.org/Abstract_link/Abstract2014-p11-30.html