EXPLORING A POTENTIAL MEANS OF MEASURING RUNNING ECONOMY ABOVE ANAEROBIC THRESHOLD

By

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Abstract

Running economy (RE) is an important predictor of endurance performance. To date, the typical methods of measuring RE involves calculating an athlete's VO_2 ($ml^{-1} \cdot kg^{-1} \cdot km^{-1}$) at a known speed during a physiological steady-state. Measuring RE for athletes who race at distances above the anaerobic threshold (AT) (800m – 5000m) is problematic because these distances are contested in conditions when physiological steady-states cannot be achieved. The current study explored the use of excess post-exercise oxygen consumption (EPOC) being added to the oxygen consumption during running for estimating RE above the AT and examined the construct validity of this measurement technique. The EPOC was measured for three minutes (fast component) from seven male and seven female varsity cross-country runners after running for three minutes at a pace of 1.0 mile per hour (MPH) above their calculated AT pace. Construct validity was established by noting theoretical associations and computing Pearson product-moment correlation coefficients between blood lactate (BLa), heart rate (HR), ventilation (VE), and excess CO_2, and RE. For the male participants, excess CO_2 had the highest correlation ($r = .629$, $p < .005$), followed by BLa ($r = .586$, $p < .001$). In the female participants ventilation had the strongest correlation ($r = .836$, $p < .001$) followed by excess CO_2 ($r = .607$, $p < .001$). These results support the construct validity for our measurement technique. The findings from this study will have implications as a performance assessment tool for researchers, coaches, and athletes.

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Chapter 1

Introduction

Introduction

Maximum oxygen uptake (VO_2max) has commonly been related to performance in competitive endurance running (Costill, 1967; Costill, 1973; Hagan, 1981; Saltin, 1967). However, research indicates that running economy (RE), defined as "the energy demand for a given velocity of submaximal running" is also a key determinant of aerobic ability (Saunders et al., 2004 p. 466) and may even be a more appropriate predictor of performance in elite runners who possess similar VO_2max values (Bransford, 1977; Conley, 1980; Daniels, 1985; Di Prampero, Capelli, Pagliaro, 1993; Krahenbuhl, 1989; Morgan, 1989; Saunders et al., 2004). For a highly trained athlete, any running distance of 5,000 meters (m) or less is run above the anaerobic threshold (AT) and requires a significant amount of contribution from anaerobic pathways (Anderson, 2013). However, as the traditional methods of measuring RE require a steady-state, to the best of our knowledge, there currently exists no way of measuring RE, or the anaerobic contributions when an athlete is above the steady-state (i.e. above AT). Following exercise, oxygen uptake remains greater than resting levels for a period of time that may differ, depending on the intensity,length of exercise and fitness capacity of the athlete. This is referred to as the excess post-exercise oxygen consumption (EPOC) (Brooks, Fahey, & Baldwin 2005) and may be the most appropriate means of quantifying anaerobic demands.

Purpose

The primary purpose of this study was to examine the construct validity of measuring RE above AT using EPOC.

Objectives

The objectives of this research include the following:

1. To examine the literature related to RE, the factors that affectRE, how RE is measured at different intensities, the physiological responses to running at different intensities, and interventions used to improve RE.
2. Assuming RE can be estimated above AT, to compare RE at the running intensities of: 1.0 MPH below, at, and 1.0 MPH. above AT, in order to determine RE in trained varsity cross-country runners.

Significance of the Study

To date, coaches and athletes have no means of accurately estimating RE above AT, despite the acknowledgement that RE remains a key determinant of running success. While RE can be measured below AT, any event with a high sustained anaerobic component (i.e. blood lactate (BLa) progressively increasing in distances up to 5000m) is problematic as there is currently no easy method of measuring the total metabolic expenditure. This research study attempted to quantify the anaerobic component through the use of EPOC being added to the actual oxygen consumption during the anaerobic effort. Construct validity was determined by analyzing correlations between our proposed methods of estimating RE above AT (integrating an EPOC value into the calculations) and BLa, heart rate (HR), ventilation (VE), and excess CO_2.

Excess CO_2. The nonmetabolic CO_2 produced. If construct validity was established through this novel method it would offer coaches and athletes a valuable tool for predicting and monitoring performance. This study may serve as a foundation for future research as it supports the use of assessing the first three minutes (quick component) of EPOC in addition to actual oxygen consumption during the anaerobic effort as an accurate reflection of the RE when running above AT.

Definitions

Anaerobic Threshold (AT). The maximum steady-state effort that can be maintained without lactate progressively increasing (Saunders, Pyne, Telford, & Hawley, 2004). Measured when the blood lactate reaches a value equal to or greater than 4.0 mmol/L (Hech et al., 1985) and/or when the Respiratory Exchange Ratio (RER) is > 1.0 (Solberg, Robstad, Skjonsberg, & Borchsenius, 2005).

Blood Lactate (BLa). A product of anaerobic glycolysis lactate, is a salt formed from lactic acid. Anaerobic exercise produces lactic acid, a byproduct of anaerobic metabolism occurring when oxygen delivery to the tissues is insufficient to support normal metabolic demand. (Baechle & Earle, 2008).

Construct Validity. The extent to which a scale, or the operationalization of a concept, performs as the theory predicts it will (Bassil & Zabkiewicz, 2014). For the purpose of this study, construct validity will be determined by analyzing correlations between our proposed methods of estimating RE above AT (integrating an EPOC value into the calculations) and BLa, heart rate (HR), ventilation (VE), and excess CO_2.

Excess CO_2. The nonmetabolic CO_2 produced through the buffering of acids by the bicarbonate buffering system. Calculated by comparing the CO_2 produced and the O_2 consumed. Excess CO_2 is predominantly caused by the bicarbonate buffering of lactic acid accumulation in blood and exercising muscles (Hirakoba, Maruyama, & Misaka, 1996).

Excess Post-Exercise Oxygen Consumption (EPOC). The summed volume of all O_2 derived processes in excess of resting VO_2 values that restore metabolic homeostasis from disturbances not only in the working muscles but all organs and tissues of the body (Gitto, 1995).

Heart Rate (HR). Number of beats of the heart per minute (Baechle & Earle, 2008).

Respiratory Exchange Ratio (RER). The ratio between the amount of CO_2 produced and O_2 consumed in one breath (Saunders et al., 2004). A RER value of 1.0 will be used as a marker of AT (Solberg et al., 2005).

Running Economy (RE). The energy demand for a given velocity of submaximal running**.** A broader and more appropriate definition for the purposes of the current study would be the amount of O_2 required or caloric expenditure to run at a given pace (Saunders et al., 2004)**.**

VO_2max. The maximum amount of oxygen that an individual can utilize during intense or maximal exercise. It is measured as milliliters of oxygen used in one minute per kilogram of body weight (Baechle & Earle 2008).

Chapter 2

Review of Literature

This literature review will examine the current knowledge that exists regarding running economy (RE). The reader will gain an insight into; RE and how it relates to performance, the reliability of RE, how RE is measured, the physiological factors that affect RE, and how body mass affects RE. Following an understanding of RE, a suggestion of a potential method to measure RE above the AT is proposed (i.e. integrating an EPOC value into the calculations). The purpose of this study is to examine the construct validity of measuring RE above AT (i.e. EPOC). Variables that are associated with RE will be discussed. These include the anaerobic metabolism of BLa, excess CO_2 production, and EPOC. In addition, how these variables are used to quantify anaerobic work and measure RE above AT will be discussed.

Running Economy and Performance

Running economy and performance are well researched, however ambiguity still remains with the physiological variability (Barnes & Kilding, 2015). Early research (Pollock, 1977) compared elite American distance runners (VO_2max 79 $ml^{-1}.kg^{-1}.min^{-1}$) and reasonably trained distance runners (VO_2max 69.2 $ml^{-1}.kg^{-1}.min^{-1}$), and concluded that elite runners had a better RE than their weaker counterparts, as VO_2 values were significantly lower in the elite runners compared to the trained runners when running at the same pace. Pollock (1979) then expressed the VO_2 values as a percent of each runners VO_2max and found that the elite runners worked at a lower percent of their VO_2max compared to the trained runners when running at the same speed. Conley (1980) examined RE in 12 elite distance runners of similar caliber, and concluded RE as a good predictor of 10-kilometer running performance. Their findings demonstrated a high correlation between RE and 10-kilometer race time (r values between 0.79 to 0.83). A study conducted by Di Prampero et al. (1993) investigated 16 runners competing in distances from 800m to 5,000m and concluded a 5% increase in RE translated to an approximate increase of 3.8% in distance running performance. Svedenhag and Sjodin (1994) reported variations in RE and performance in elite distance runners (VO_2max 75 $ml^{-1}.kg^{-1}.min^{-1}$) where they varied their training protocols to include slow distance, uphill, and interval training over a 22-month period. Subjects significantly reduced their reliance on the contribution of VO_2 when running at speeds of 15-20 kilometers per hour. All of these studies indicate the relevance of RE in predicting performance. More recently, Weston (2000) explored the role of ethnicity where they compared RE and performance of Kenyan and Caucasian distance runners. The study investigated 16 (eight Kenyans and eight Caucasians) participants that had average 10-kilometer race times ranging from 32-37 minutes). They reported that Kenyans had 13% lower VO_2max than their Caucasian counterparts; however, had similar 10-kilometer race times due to their 5% enhanced RE. The study also reported that the Kenyan runners finished the 10-kilometer race at a higher percentage of their VO_2max but with similar BLa to that of the Caucasian runners. The greater RE found in the Kenyan runners is believed to be from greater muscle oxidative enzyme activity, and perhaps from external factors including different training styles as result of greater motivation Weston (2000). This enhanced ability also implies that if the amount of VO_2 required to run a range of running velocities can be reduced, an enhanced performance should be achieved. In summary, RE is an appropriate predictor for distance running performance and may provide insight into why some ethnic groups might achieve higher levels of performance in distance running (Saunders et al., 2004).

Treadmill Running and Running Economy

Running economy is measured by analyzing a VO_2 steady-state while running on a motorized treadmill in standard laboratory conditions (Saunders et al., 2004). Although treadmill running does not offer a perfect race simulation, it does provide a strong predictor of how economical a runner is and how RE is altered over time (Saunders et al., 2004). For example, wind resistance is eliminated, and consequently comparing treadmill-running data over ground running data should be carefully considered prior to generalizing the results to athlete populations (Daniels, 1985; Daniels, Daniels, & Baldwin, 1986). Pugh (1970) suggested that 8% of the total amount of energy required in a 5000 m race was utilized overcoming wind resistance. Davis (1980) estimated that the amount of energy required to overcome wind resistance in a marathon was approximately 2%. This 6% variation between the two studies may be due to the longer distance of the marathon, the fact that a 5,000m race takes place on a track and a marathon on a road (Davis 1980). However, when the velocity of the tailwind is equal to running velocity, over ground VO_2 values were equivalent to treadmill VO_2 values (Daniels et al., 1986). The forces that are generated and absorbed from treadmill running typically require a reduced amount of energy compared to running on land (Riley et al., 2008). The reduction of required energy experienced in treadmill running is chiefly due to the elastic suspension of the treadmill (Riley et al., 2008). Although there are differences between treadmill running and over ground running, reports from Saunders and colleagues (2004) indicated that RE can be appropriately measured using a treadmill (Saunders et al. 2004), and concluded that interventions that affect RE measured on a treadmill will have a similar affect when running over ground (Saunders et al.2004).

Reliability of Running Economy

A study conducted by Daniels, Scardina, and Hayes (1984) found an 11% variation in the stability of RE in 10 experienced male runners running at a speed of 16 kilometers per hour. This variability existed even after controlling for footwear and rest. However, more recent well-controlled reliability studies measuring RE have demonstrated an intra-individual variation between 1.5-5% (Morgan, 1988; 1994; Pereira, Freedson & Maliszewski, 1994; Pereira & Freedson, 1997). The larger variation in RE established by Daniels and colleagues may be due to the fact that they only controlled testing equipment, speed, and footwear, whereas the other studies (Morgan, 1988; Brisswalter, Legros, Daily, 1994; Pereira & Freedson, 1994; Pereira & Freedson, 1997) controlled additional factors including; relative intensity of the workload, and diet. These factors may influence the intra-individual variations in RE as it has been documented that a higher intensity of running will imply a lower RE, and diet may affect the onset of BLa, thus affecting RE (Saunders et al., 2004) Previous findings have demonstrated that a d the VO_2 obtained at the onset of BLa was significantly lower after a high carbohydrate diet (Saunders et al., 2004). Additionally, it has been proved that BLa makes a runner less economical, as the BLa compromises running form (Hoff et al., 2016).

Factors that Affect Running Economy

Given the importance of RE on performances in both middle- and long-distance running events, there has been great efforts to explore factors that affect RE (Saunders et al., 2004). Typically, RE is determined by measuring the steady-state consumption of oxygen (VO_2). Factors that affect RE are; training, environment, physiology, biomechanics, and anthropometry (Saunders et al., 2004). These factors are presented in figure 1, adapted from Saunders et al. (2004).

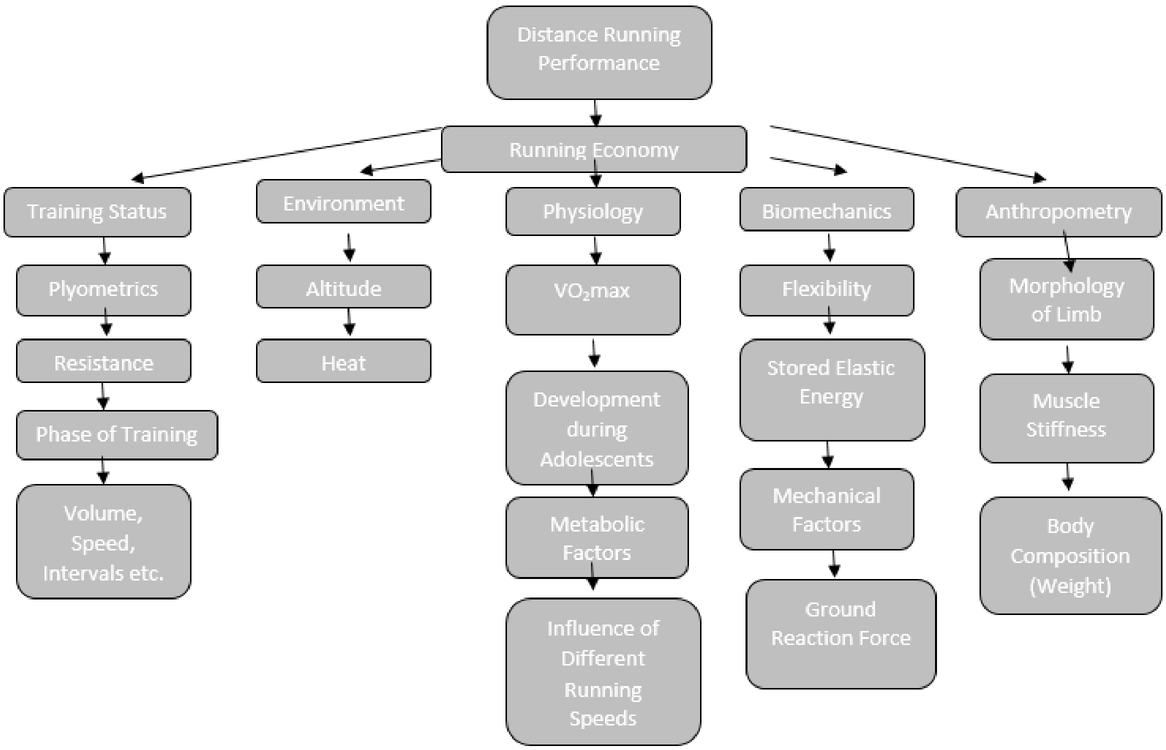

Figure 1: Factors Affecting Running Economy (adapted from Saunders et al., 2004).

Despite the vast amount of available research investigating factors affecting RE there is relatively few studies that have examined how various running speeds influence RE, especially at running at speeds above the AT.

Physiological Factors Affecting Running Economy

Variations in physiological components such as core temperature (Ctemp), heart rate (HR), ventilation (VE), and BLa may have an association with changes in RE (Adams & Bernauer, 1968; Armstrong & Gehlsen, 1985; Morgan, Baldini, Martin, 1989; Thomas, Fernhall, Blanpied, 1995). Thomas et al., (1999) observed an non-statistical increase in Ctemp, BLa, and HR, in relation to a decrease in RE when subjects ran at a constant treadmill speed of approximately 80-85% of their VO_2max for five kilometers. However, an increase in VE was statistically correlated with a decrease in RE (r = 0.69; $p < 0.05$), thus implying a greater oxygen cost linked with the decrease in RE. A higher Ctemp increases the amount of VO_2 needed at a given speed (Brooks, Hittelman, & Faulkner 1971a; Brooks, Hittelman, & Faulkner 1971b; MacDougall, Reddan, & Layton, 1974; Saltin & Stenberg, 1964). VO_2 intake is typically increased due to a higher metabolic demand associated with an increased; blood circulation to the periphery, VE, and sweating response to maintain Ctemp. These additional physiological demands require greater energy expenditure and the consequence is an indirect decrease in RE. However, this was contradicted by Rowell et al., (1969) who suggest the mechanical efficiency of muscle actually improves when Ctemp is slightly raised, reducing VO_2 demands by “equal or greater amounts than the increase by changes in the cost of sweating, circulation, and VE” (Rowell et al., 1969 p.718). Another factor that appears to influence RE is muscle composition, as slow-twitch muscle fiber is associated with better RE, (Bosco, Montanari, & Ribacchi, 1987; Kaneko, 1990; William & Cananagh, 1987) thereby indicating that speed of muscle fiber contraction may impact RE. It is believed that the association between slow twitch fibers and better RE is a result of these fibers being more aerobically inclined which promotes more efficient aerobic metabolism (Willams & Cannagh 1987).

Some authors, (Bransford, 1977; Conley, 1984; Sjodin, Jacobs, & Svedenhag, 1982) but not all (Costill, Thomason, & Roberts, 1973; Daniels, Oldridge, & Nagle, 1978; Dolgener, 1982) have shown improvements in RE, consequent to training interventions. Daniels et al. (1978) demonstrated that the subjects’ initial fitness level is crucial when examining training and thereby RE alteration. Previous studies have determined that trained subjects are more economical compared to untrained subjects (Bransford, 1977; Daniels, 1985; Dolgener 1982; Krahenbuhl & Pangrazi, 1983; Mayers & Gutin, 1979) and that long distance runners are more economical than middle distance runners at speeds below 19 kilometers per hour (Daniels, 1985; Pollock, 1977). It is thought that the long distance runners are more economical as endurance training leads to increases in the morphology of skeletal muscle mitochondria (Saunders et al., 2004). As a result of training, a rise in the respiratory capacity of skeletal muscle can occur. This rise allows trained runners to use less oxygen per mitochondrial respiratory chain when running at submaximal running speeds (Saunders et al., 2004). These physiological responses invoke enhancements in RE, slower consumption of muscle glycogen in the working muscles, and reduced disturbances in homeostasis. The specificity of training principle implies that to become better at a particular exercise or skill, you must perform that exercise or skill (Powers & Howley, 2009). These findings reinforce the specificity of training principle, as the long distance runners were more economical than the middle distance runners at the speeds that they more frequently trained in (Daniels, 1985; Pollock, 1977). These findings may provide insight into how RE could be improved at intensities above the AT. Thomas et al. (1995) proposed that subjects training to improve RE should seek interventions that are known to improve the physiological factors of HR, VE, BLa, and Ctemp regulation in order to decrease the energy demand related to these parameters. However, the most appropriate interventions to improve these physiological factors are still debated (i.e. interval training, long slow running, altitude training, specific weight training) (Thomas et al., 2005).

Physiological Factors Affecting Running Economy above the Anaerobic Threshold

Several forms of training seem to have a strong and positive impact on RE. Forms of training include tapering, hill training, strength training, plyometric work, and pace-specific training (Anderson, 2013). Using 16 recreational male runners and an eight-week training period, it was established that running at a specific effort (approximately 75% max HR) improves RE at the chosen training speed; however, the mechanisms for this are not well understood (Beneke & Hutler 2005). Runners who favour their training towards running long distances at moderate speeds tend to become more economical at moderate speeds, while runners who train at quicker tempos tend to enhance their economy at faster speeds. Although specificity of the training can explain changes in RE, the physiological improvements are still not well understood (Beneke & Hutler 2005; Daniels & Daniels 1992). The specificity of training has important implications. For example, a 1500 m runner should include a significant amount of training at the goal 1500 m pace in order to optimize economy at their desired intensity, and marathoners should insert segments paced at their marathon goal speeds into their long runs (Anderson, 2013).

The minimum velocity for which VO_2max is reached is known as the vVO_2max (Anderson, 2013). Running economy is a variable that is built into vVO_2max, as a result a high vVO_2max automatically means a good RE. (Anderson, 2013).

Therefore, training techniques that increase vVO_2max also tend to improve RE. One way to optimize vVO_2max and RE, is to train at velocities near vVO_2max (Anderson, 2013). These findings are consistent with results from Billat and colleagues (1999), where participants were trained with vVO_2max based training two-days per week for four-weeks, and they observed no improvement in VO_2max, a 3% increase in vVO_2max, and a 6% improvement in RE. This may be a result of subjects achieving their genetic performance level regarding VO_2max, however are more comfortable running at this intensity, thus, they can run at a faster speed without increasing the VO_2max.

Anaerobic threshold, is a measurement that includes information on lactate dynamics, and thus indirectly relates to oxygen use and running economy (Anderson, 2013). Although research has shown that running at speeds above AT can improve RE, to date there is no means of assessing RE while the runner is above AT. Most information in the literature relates to testing at a speed that is below the AT (Anderson, 2013).

Interventions to Improve Running Economy

Many physiological factors (VO_2max, metabolic factors, running speeds) and biomechanical variables (flexibility, elastic stored energy, mechanical factors, ground reaction force) influence RE. However, a limited amount of research exists regarding the improvement of RE and running performance via changing these factors (Bailey & Pate, 1991). Diverse training methods demonstrate improved RE in untrained and moderately trained subjects, with trained runners having a better RE compared to their untrained or less trained counterparts (Saunders et al., 2004). However, for highly trained runners who already have a strong RE, improvements are difficult to obtain as there is less room for improvement. Strength training, altitude exposure, and training in a warm to hot environment are potential training parameters that can improve RE in both trained and untrained subjects. (Saunders et al., 2004).

Strength training. Strength training alters anaerobic characteristics such as the ability to produce high amounts of BLa and the production of faster leg turnover rates (Bulbulianm, Wilcox & Darabos, 1986; Hournard, Costill, & Mitchell, 1991). Millet and colleagues (2002), demonstrated that training with heavy weights (90 % of one repetition max) in combination with endurance exercise minimally enhanced running performance and improved RE in well-trained triathletes (VO_2max $ml^{-1}.kg^{-1}.min^{-1}$). Workouts consisted of two warm-up sets (at the participants chosen weight), and three to five sets to failure of three-five repetitions, focusing on lower limb muscles (hamstring curls, leg press, seated press, parallel squat, and heel raises) (Millet et al., 2002).

Explosive strength or plyometric training in theory should improve RE via higher force generation without a huge increase in anaerobic and aerobic energy demand (Paavolainen, Hakkinen, & Hamalainen, 1999). These investigators demonstrated that nine weeks of plyometric training, consisting of two sessions per week, lasting 15-90 minutes, that included various jumping exercises, bilateral movement, drop and hurdle jumps, and one legged jumps was sufficient to increase RE by 8%, and reduce five kilometer running time by 3% without a change in VO_2max (Paavolainen et al., 1999). These improvements were believed to result from of specific neural adaptations such as heightened motor unit activation, and an increase in muscle –tendon stiffness, thus allowing the body to store and utilize elastic energy in a more efficient manner (Paavolainen et al., 1999). However, to date, there is still a limited amount of research regarding the effects of plyometric training on elite (VO_2 max >70 $ml^{-1}.kg^{-1}.min^{-1}$) distance runners.

Altitude training. Altitude training on endurance performance is well researched (Bailey, Davies, & Romer, 1998; Ashenden, Gore, & Dobson, 1999; Ashenden, Gore, & Dobson, 2000, Gore, Hahn, & Aughey, 2001). The central dogma in the athletic community is that altitude training can increase sea-level athletic performance (Dick, 1992; Levine & Stray-Gundersen; 1997; Wibler, 1995). It is believed that the benefits may derive from hematological changes (more red blood cells) and local muscular adaptations (improved skeletal muscle buffer system (Gore et al., 2001). The traditional method of altitude training is to live and train at moderate altitude (1500-3000m); however, other methods and combinations have been tried including living high and training low, living low and training high (Rusko, 1996). Results of these studies are mixed on their findings regarding altitude exposure and an improvement in RE. Three studies (Telford, Graham, & Sutton, 1996) (Levine & Stray-Gundersen 1997) (Bailey et al., 1998) demonstrated no significant differences in VO_2 demands during a moderate intensity exercise post-altitude exposure. On the other hand, other studies have demonstrated improved RE post-altitude exposure in highly trained runners (Katayama, Matsuo, & Ishida, 2003; Katayama, Sato, & Matsuo, 2004; Saunders et al., 2004). However, the ambiguity between studies may be a result of the duration participants remained at altitude (10 days - 30 days), the altitude that participants lived at (1700m - 3000m, and the technique used (live- high train-high, live-high train-low).

Mechanisms that have been proposed as the means of improving RE following exposure to altitude include decreased cost of VE, greater regeneration of adenosine triphosphate (ATP), greater amount of hemoglobin present in the red blood cells, and greater carbohydrate utilization for oxidative phosphorylation (Green, Roy, & Grant, 2000). However, altitude exposure has not been extensively researched relative to RE. Additionally the studies that have been conducted have produced mixed results on the effect altitude training has on RE.

Training in hot environments. Training in hotter environments is another intervention that may be effective at improving RE (Saunders et al., 2004). The belief is that the efficiency of the working muscle may increase because of the mildly elevated CTemp. It is believed that bouts of exercise in the heat may attenuate the thermoregulatory response (increase in ventilation, circulation, and sweating) and decrease the energy requirements related to exercising in the heat (Saunders et al., 2004). These heat-related adaptations have been shown to have a potential increase in plasma volume by up to 12% (Svedenhag, 2000). The increase in plasma volume aids in the maintenance of stroke volume, thus, minimizing myocardial work (Bailey & Pate, 1991).

The adaptations (attenuated thermoregulatory response, increase in plasma, improved efficiency of working muscles) that take place from running in the heat could also allow runners to run at any given speed with a lower HR and CTemp; both factors are associated with an improved RE (Thomas et al., 1995). These limited findings support the idea that training in moderate heat may improve RE during performance at normal temperatures; however, since research in this area is limited, no conclusions can be drawn as of yet.

Body Mass and Running Economy

Running economy may be conveyed as a ratio of a runners' VO_2 (L/min) divided by their body mass (BM) in kilograms (Davies, Mahar, Cunningham, 1997) while running at a given speed. However, VO_2 during running does not correspondingly escalate to BM (Bergh, Sjodin, Forsberg, 1991). For example, VO_2 per kilogram of BM is greater in children than adults (Asrtrand, 1952; Daniels, 1985; Unnithan & Eston, 1990). Berg et al. (1991) proposed that a higher submaximal VO_2 observed in children is associated with differences in body size and not exclusively growth and maturation.

Running economy can also be affected in the pattern of distribution of mass in the body (Saunders et al., 2004). For instance, carrying mass distally will increase the aerobic demand to greater degree than carrying mass more proximal to the center of the body (Catlin & Dressendorfer, 1979). Catlin and Dressendorfer (1979) were the first to show that for every 100 grams (g) of weight added to the feet there is approximately a 1% increase in energy expenditure. In their study participants ran with shoes weighing 870g and again with shoes weighing 520g. The 350g difference increased the metabolic energy demand by approximately 3.3%.

Potential Methods for Estimating Running Economy above Anaerobic Threshold

A typical method to quantify RE involves running on a treadmill at a steady-speed and measuring the VO_2 used (Fletcher, Esau, Macintosh, 2009). Most studies express RE as the relative VO_2 ($ml^{-1}.kg^{-1}.min^{-1}$) at a known speed. Fletcher and colleagues (2009) suggested a different approach to measure RE and argued that it could be more appropriate to express RE as the VO_2 required to run a certain distance ($ml^{-1}\cdot kg^{-1}\cdot km^{-1}$). It has also been argued that expressing RE as caloric unit cost ($ml^{-1}\cdot kg^{-1}\cdot km^{-1}$) may be more sensitive to a change in velocity (Fletcher, Esau, Macintosh, 2009).

Although RE has been expressed differently, the majority of studies quantified RE by measuring the O_2 cost per minute (Saunders et al., 2004). Therefore, we aimed to quantify RE by measuring the O_2 demand per minute regardless of the pace. When an individual begins to run at levels above AT, the O_2 demand would only partially reflect the total metabolic costs, as by definition, some contributions are coming from anaerobic pathways. Therefore, we hypothesized, that the RE above AT could possibly be quantified, and keeping anaerobic contributions in mind, it may be possible to accurately quantify RE above AT. The anaerobic metabolites will be discussed in the sections below.

Excess Post-Exercise Oxygen Consumption

At the onset of exercise VO_2 will not increase instantly, thus leading to a dependency on anaerobic mechanisms to support the work demand (Gastin, 2001; Walsh et al., 2001). One of the anaerobic mechanisms, phosphocreatine (PC), is used during the first two to seven seconds in order to form ATP (Brooks, Fahey, & Baldwin 2005). This anaerobic contribution to the complete energy demand of exercise is known as the oxygen deficit (Hill, 1924; McArdle, Katch, & Katch 2007). Post-exercise, oxygen uptake remains greater than resting levels for a period of time that may differ, depending on the intensity and length of exercise. Post-exercise oxygen uptake has been called the oxygen debt (Hill, 1924; McArdle, Katch, & Katch 2007), recovery O_2 (McArdle, Katch, & Katch 2007), or the excess post-exercise oxygen consumption (EPOC) (Brooks, Fahey, & Baldwin 2005). A summary of oxygen consumption at the onset of exercise and post-exercise can be viewed in figure 2.

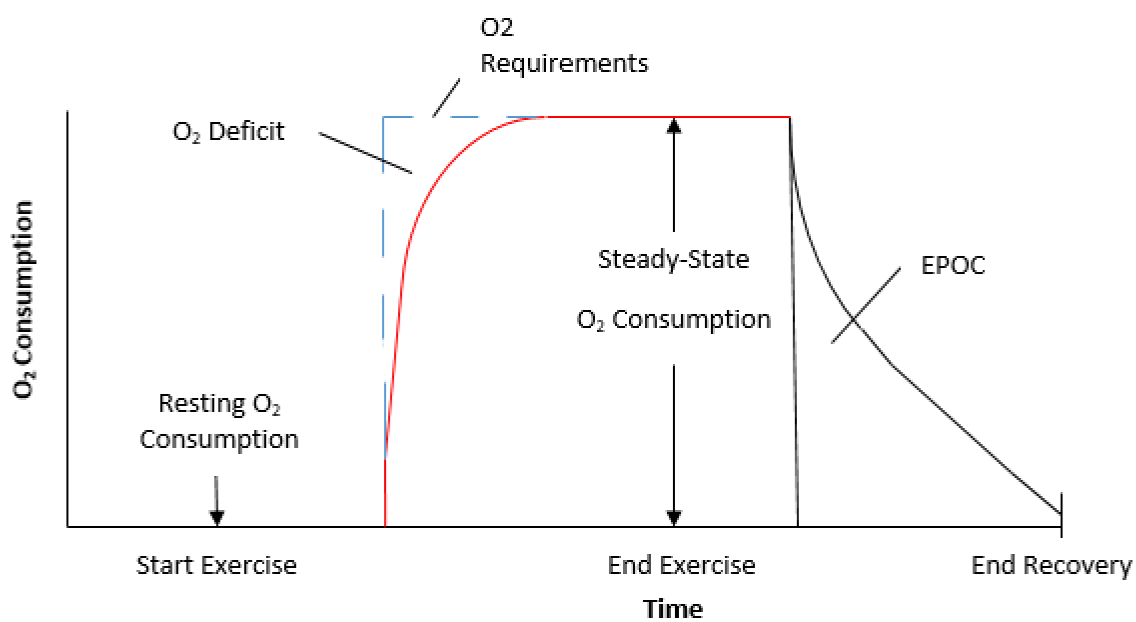

Figure 2: Excess Post-Exercise Oxygen Consumption adapted from (Baechle & Earle, 2008).

Simply stated; the EPOC is the oxygen uptake above resting values, used to restore the body to the pre-exercise condition (Stainsby & Barclay, 1970). For the purpose of this research project, we will refer to it as EPOC as it is the most descriptive term and perhaps the most appropriate (Brooks, Fahey, & Baldwin 2005 p.226).

Post-exercise the oxygen intake will remain elevated in order to restore PC in muscles (Bahr, 1992; Gaesser and Brooks, 1975). Another probable explanation for EPOC is restoration of O_2. The amount of O_2 stored in the blood (bound to hemoglobin) and muscle (bound to myoglobin) is not an enormous amount, however, it does need to be replenished following exercise. The replenishment of O_2, most likely occurs within two to three minutes post-exercise (Bahr, 1992; Stainsby & Barclay, 1970). Lactic acid removal has also been suggested as a reason for EPOC (Plowman & Smith, 2007). Around half of the lactic acid is removed after 15 minutes, and most is removed after an hour into the recovery phase (Gledhill, Muligan, Saffrey, Sutton, & Taylor, 2007). Other proposed explanations for EPOC include elevated cardiorespiratory function, elevated hormonal levels (epinephrine and norepinephrine), and elevated body temperature (Plowman & Smith, 2007).

Once adequate oxygen is available, lactic acid must be catabolized completely into carbon dioxide and water (Brooks, Fahey, & Baldwin 2005). After exercise has ceased, additional oxygen is required for a number of reasons such as to metabolize lactic acid, and for the replenishment of: ATP, PC, and glycogen. Additionally, oxygen aids in the restoration of any oxygen molecules borrowed from hemoglobin, myoglobin, air in the lungs, and body fluids (Brooks, Fahey, & Baldwin 2005).

Excess post-exercise oxygen consumption can be broken down further into fast and slow components (Gledhill et al., 2007). The fast component (alactacid oxygen debt) is the amount of oxygen necessary to synthesize and restore muscle phosphagen stores (ATP and PC). Whereas the slow component refers to the amount of oxygen required to remove lactic acid from the muscle cells and blood (Gledhill et al., 2007).

Metabolic responses to exercise are typically studied using indirect calorimetry, such as oxygen consumption (Brooks, Fahey, & Baldwin 2005). The limited number of attempts to validate indirect calorimetry, as a measure of metabolic rate on exercising individuals has produced excellent results (Brooks, Fahey, & Baldwin 2005).

Withers and colleagues (1991) explored how EPOC was affected following 160 minutes of running at 70% of participant's VO_2max. The average EPOC value was approximately 32.4 liters (32.4L x 5 calories = 162 calories), meaning that this was a considerable contribution to complete energy expenditure. Another study conducted by Gore and Withers (1990) found average EPOC values to be 14.6L (14.6L x 5 calories = 73 calories) after subjects had completed an 80 minute run at 70% of their VO_2max. As a result of this phenomenon, it will be necessary to keep the caloric unit cost of the EPOC in mind when attempting to express RE as the total caloric unit cost ($kcal.kg^{-1}.km^{-1}$).

The measurement of EPOC is thus complicated and will require a measurement of O_2 consumption for a certain amount of time post-exercise. However, the amount of time required is unclear. Although EPOC may provide some theoretical background and research potential it currently does little from a practical coaching perspective, however one option is that EPOC can be predicted by using HR (Rusko, Pulkkinen, Saalasti, Hynynen, & Kettunen, 2003).

The prediction of EPOC is based on HR derived data. Current intensity, quantified as the % VO_2max, and duration of exercise, measured as the time between sampling points, and EPOC from a preceding EPOC sampling point are used in order to evaluate the approximate EPOC at any given moment. The $_{(t)}$ is the recovery time post-exercise. The equation is expressed as:

$$\mathbf{EPOC_{(t)} = f(EPOC(t-1), exercise\_intensity(t), \Delta t)\ (Saalasti\ 2003).}$$

This prediction equation has been shown to be reliable r = 0.79 (Rusko, Pulkkinen, Saalasti, Hynynen, & Kettunen, 2003).

Blood Lactate

Cellular respiration is a process of cells producing energy in the form adenosine triphosphate (ATP) (Baechle & Earle, 2008). There are two kinds of cellular respiration; aerobic and anaerobic (Baechle & Earle, 2008). The pathway that the cells use in order to produce energy depend on the availability of O_2. During anaerobic respiration, there is not enough oxygen, and the cell relies on breaking down glucose (Baechle & Earle, 2008). One of the byproducts of breaking down glucose is lactic acid. When an athlete begins to perform above the anaerobic threshold, BLa is produced at a rate quicker than the body is capable of clearing it (Goodwin et al., 2007). Blood lactate is often used as a tool to estimate changes in aerobic metabolism in athletes in order to predict performance (Goodwin et al., 2007). Studies have used BLa as a means of estimating aerobic metabolism and the amount of contributions from anaerobic pathways (Goodwin et al., 2007). The typical resting BLa levels range from 1-2.5 mmol/L, and 4.0 mmol/L is a widely accepted threshold suggesting the onset of anaerobic metabolism (Hech et al., 1985). However, when an individual exercises at supramaximal or maximal intensities, levels can be as high as 15-25 mmol/L and typically stay elevated for three to four minutes post-exercise (Goodwin et al., 2007). Although a recent study (Hoff et al., 2016) established that an increase in BLa negatively impacts RE. To the best of our knowledge BLa has not been used to estimate performance status or performance abilities in runners working above AT. Therefore, BLa could be considered a tool to estimate the onset anaerobic metabolism and its impact on performance. Additionally, BLa is a practical tool for coaches and athletes to assess performance when running above AT.

Pulse Oximetry

Pulse oximetry is a noninvasive method for estimating an individual's percent oxygen saturation (SpO_2). Percent oxygen saturation is best described as an indicator of the percentage of hemoglobin saturated in oxygen present in the blood (Schutz, 2001). It is typically defined as a ratio of saturated oxygen compared to the total concentrations of hemoglobin found in the body (Schutz, 2001). SpO_2 has been used to monitor and estimate athletic performance (Berry & Seitz 2012). On average, healthy, resting, individuals will experience SpO_2 levels ranging from 97-99% SpO_2 (Schutz, 2001); although, it is not uncommon for individuals to experience levels ranging from 85-90% during intense exercise (Berry & Seitz 2012). SpO_2 can also be used to monitor athletic performance (Berry & Seitz 2012; Schutz, 2001); however, to the best of our knowledge has not been used to estimate RE, nor to estimate performance above AT, hence, pulse oximetry will allow us to estimate the oxygen delivery above AT. As pulse oximetry is noninvasive, relatively inexpensive, and portable, pulse oximetry may be suitable for coaches and athletes to practically estimate athletic performance.

Respiratory Exchange Ratio

The respiratory exchange ratio (RER) (CO_2 production/O_2 uptake) in an indirect measurement that shows the muscle's oxidative capacity to acquire energy (Bellar & Judge 2011; Ramos-Jimenez et al., 2011). As exercise intensity increases the value of the RER rises and when estimated under steady-state circumstances can be used to indirectly estimate the role of carbohydrate and fats to the overall energy expenditure (Ramos-Jimenez et al., 2011). The RER is a fitness indicator in trained individuals (Ramos-Jimenez et al., 2011), and can also be used as an appropriate estimate of an individual's AT (Solberg et al., 2005). Although RER has been used gage athletic performance, to the best of our knowledge RER has not been used to estimate RE or to estimate performance above AT. Although, the estimation of RER typically requires a laboratory to examine the expired gases, it may still provide some practical application to coaches and athletes. This may be a useful measure to assess an athlete before a competitive season and post-competitive season in order to estimate the variations in the muscle's oxidative capacity at various speeds.

Excess Carbon Dioxide

In 1930, Harrison and Pilcher noted that excess carbon dioxide (excess CO_2) is released from bicarbonate (HCO3-) when acids form during anaerobic metabolism are buffered. Since then, it has been well accepted that the volume of excess CO_2 output, predominantly caused from bicarbonate buffering of lactic acid accumulation in exercising muscles and in blood would correlate significantly with BLa used as fuel (Hirakoba et al., 1996).

Following exercise, lactic acid is spread throughout and buffered by rather than at the active muscle (Yano, Yunoki, Ogata, & Matsuura, 2005). The buffer action in the extracellular fluid is primarily dependent on the bicarbonate buffer system, which can be observed as excess CO_2, and expressed in the equation $H^+ + HCO_3^- \rightarrow H2CO_3 \rightarrow H_2O + CO_2$ (Yano, 1987). It is estimated that approximately 90-94% of the hydrogen ion produced in the working muscle mass from the disassociation of lactic acid will be buffered instantly by the bicarbonate system producing excess CO_2 and water (Wasserman, Beaver, & Whipp, 1986).

Excess CO_2 will be created as long as the rate of lactic acid production is increasing as there will be additional hydrogen ions to buffer (Wasserman et al., 1986). As a result, the removal of lactic acid from the muscle during exercise to the whole body throughout recovery, through the buffering action can be measured using excessive CO_2 expiration (Yano et al. 2005). Studies (Hirakoa et al., 1996; Yano et al.2005) have found that excess CO_2 as a physiological index for assessing performance is as good a measure as peak BLa levels. Calculated by comparing the CO_2 produced and the O_2 consumed.

Anaerobic metabolism begins to contribute during heavy/intense exercise (Bangsbo, Gollnick, & Graham, 1990; Spiret, 1992). Exercise physiologists have quantified anaerobic energy expenditure by measuring muscle biopsies of anaerobic metabolites plus oxygen uptake during exercise or EPOC post-exercise (Scoot & Kemp, 2004). Indirect estimates of the anaerobic contribution to energy expenses can be determined; however, these methods (excess post-exercise oxygen consumption, BLa) are debated because metabolic efficiency can change with changes in exercise intensity and duration (Scott & Kemp, 2004). Calculating the efficiency of rapid glycolytic ATP and lactate production can be challenging, but estimates have ranged from 31% to 47% (Gonzalez-Alonso, Quistroff, Bangsbo, & Saltin, 2000; Krustup, Ferguson, Kjaer, & Bangsbo, 2003). Therefore, it may be possible to quantify the anaerobic demands using the EPOC and BLa.

Conclusion

Running economy is a reliable and appropriate predictor of mid-distance, and distance running performance (Saunders et al., 2004). There are various factors that affect RE, including; biomechanical factors, training status, environment, anthropometric, and physiological factors (Saunders et al., 2004). One of the physiological factors is influence of different running speeds on RE (Saunders et al., 2004). As a result, coaches and athletes seek interventions to improve RE, including altitude training, strength training, and training in hot environments. Although it is known that running at speeds above AT improve RE (Anderson, 2013), to the best of our knowledge there is no current means of measuring RE when running at speeds above the AT.

Chapter 3

Methodology

A total of fourteen participants (seven male and seven female) were recruited and evaluated in this study. Participants were a convenience cohort of varsity cross-country and distance track athletes Participants were screened by a Physical Activity Readiness Questionnaire (Adams, 1999) (Appendix A), a department specific Maximal Exertion Questionnaire (Appendix B), and a department specific First Step Running Questionnaire (Appendix C). Prior to data collection, ethical approval was granted from the University Research Ethics Board (Appendix D) and biosafety ethical approval was received for the BLa sampling from the University Biosafety Committee (Appendix E).

Testing Procedures

Testing protocol. The procedure required the participants to attend two separate testing sessions each lasting between 45 and 60 minutes in duration, with a minimum of three-days, and a maximum of 14-days between testing sessions. To ensure reliability participants were asked to observe the following guidelines prior to testing:

- Not to eat a substantial meal three hours before the test.
- To abstain from alcohol 24-hours before the test.
- To abstain from coffee, tea, or other caffeine sources at least one hour before the test.
- To abstain from vigorous training or high intensity physical work for 24-hours prior to the test.
- To wear the same shoes to each testing session.
- To ensure that they are in a fully hydrated state when reporting to the laboratory.

Research Design

Exploratory research is primarily concerned with the examination of relationships between variables as common branches include cohort study and correlational design (Bassil & Zabkiewicz, 2014). As a cohort study typically examines one specific type of group, and a correlational design is primarily concerned with identifying associations between variables, we propose that our design has elements of both designs. As we studied a specific cohort of cross-country and track runners to examine how their RE was influenced at specific speeds.

Procedures

Baseline measurements. Prior to each testing session, participants had baseline measurements taken and recorded. Participant's body mass (kg) was measured using a My Weigh MD 500 Digital scale™ (My Weigh Canada, Vancouver, Canada), and height (cm) was measured using a Tanita HR – 100™ stadiometer (Tanita Corporation of America, Inc, Arlington Heights, United-States). Resting HR was taken using a Polar RS 400 Heart Rate Monitor (Polar Electro Inc. Kempele, Finland) and chest strap at the beginning of each testing session. Additionally, a resting blood pressure was measured and recorded by a Registered Nurse using a blood pressure cuff (Professional Series AMG medical Inc. Montreal, Canada) and stethoscope (Littmann 2296. 3M™ Littmann® Stethoscopes, Chelsea, United-States)

Warm-up. Both male and female participants performed a standardized warm-up prior to testing. The warm-up consisted of running for 10-minutes at 5.0 MPH. The general warm-up was designed to increase the core body temperature and ensure that the participant felt ready for testing.

The first testing session. Following the baseline measurements, participants were fitted with a Hans Rudolph Inc. 7940 series mask (Hans Rudolph Inc. Shawnee Mission, KS, USA) and connected to an AD instruments metabolic analyzer (AD Instruments Pty Ltd, Castle Hill, Australia). Using the metabolic analyzer allowed for inspired and expired gases to be continuously monitored and recorded during the VO_2max protocol. At this time, the researchers also ensured that a NONIN GO1 Achieve fingertip pulse oximeter (Nonin Medical Inc. MN, USA) was placed on one of the participant's fingers from the right hand. This allowed for SpO_2 to be monitored and recorded every minute. Following the 10-minute warm-up, participants underwent a VO_2max test that was similar to the one described by Bouchard, Taylor, and Dulac (1982) (Appendix H). The initial treadmill speed was set at 6.0 MPH for females and 7.0 MPH for males and increased 0.5 MPH every-minute. The treadmill grade remained horizontal until the subject completed three workloads past the RER value of 1.0 or a BLa level equal to or greater than 4.0 mmol/L was achieved. At that time, the speed remained constant and the grade of the treadmill increased 2% every minute. Participants continued to run until exhaustion or it was unsafe to do so. Blood lactate was monitored and recorded every minute using a Lactate Scout portable blood analyzer (SensLab GmbH Lepzig, Germany). This was done with a Registered Nurse and an assistant using the same technique every time. Finger-stick capillary blood was collected from participants. As part of this protocol (Appendix J), the fingertip was cleaned with 70% isopropyl alcohol and allowed to air dry. A drop of capillary blood was obtained by using a single-use disposable lancet (Arkray Multi-Lancet II device, Arkray, Mineeapolis, United-States) to pierce the side of the fingertip. Blood was then transferred to the handheld lactate Scout analyzer (SensLab GmbH Lepzig, Germany). Following the VO_2 max protocol participants rated their perceived exertion using a 6-20 Borg Rate of Perceived Exertion

Scale (RPE) (Borg, 1982) (Appendix I) and started a cool-down (described below). The primary purpose of the VO_2 max test was to calculate running speed at AT for each participant as well as assess the cardiorespiratory fitness for each participant.

The second testing session. Participants had baseline measurements taken and recorded at the start of the second testing session. These baseline measurements were measured and recorded in the same manner as the first testing session. Following the baseline measurements participants were prepared for testing in the same manner as the first testing session. During the warm-up expired gases were recorded and monitored. A BLa value was taken at the end of the 10-minute warm-up. Following the warm-up, participants ran at three different running speeds for three minutes each. The running speeds were approximately 1.0 MPH below their AT, at their AT, and 1.0 MPH above their AT. Heart rate and SpO_2 were monitored and recorded every minute. At the end of each three-minute stage participants were asked what their RPE was using a 6-20 Borg Scale (Borg 1982) (Appendix I). The RE protocol can be viewed in table 1 below.

Table 1. Running Economy Assessment Protocol.

Time (minutes)	Pace
10	Warm-up (5 M.P.H.)
3	1 M.P.H. below AT
3	at, AT
3	1 M.P.H. above AT
10	Cool down (5 M.P.H.)

AT = Anaerobic Threshold, MPH = Miles per Hour

At the conclusion of the three-minute stages a BLa sample was also taken and recorded. Following each of the three-minute stages, participates began a cool down at 5.0 MPH. During the cool down, the expired gases were monitored and recorded. Blood lactate values were taken and recorded every-minute during the cool down. The last minute of the three-minute stage was used to calculate RE. Three minutes is adequate time for a steady-state to be achieved, especially in a trained population (Morgan, Martin, & Krahenbuhl, 1989). Furthermore, a steady-state was declared if the increase in O_2 was <100 ml over the last minute (Fletcher, Esau, Macintosh, 2009).

Cool down. Following both testing protocols, participants performed a 10-minute cool down that consisted of 10-minutes of running on the treadmill at 5.0 MPH. Once the running was complete participants performed static stretches of their choice until the participants' HR was below 99 beats per minute and their blood pressure was below a value of 144/94 (Tremblay et al., 2011).

Running Economy Calculations above Anaerobic Threshold

During the three minute workloads 1.0 MPH below and at AT pace (i.e. during physiological during steady-states), RE was calculated by analyzing the oxygen consumption (numerator) expressed as ($ml^{-1} \cdot kg^{-1} . min^{-1}$) and assessing the workload (denominator). The calculation of RE above AT was calculated the same however, three minutes of EPOC, post-exercise, was added to the oxygen consumption, to more accurately reflect the O_2 demands.

Statistical Analysis

In order to address the purpose of this study the following statistical analysis was used:

Pearson correlations between speed and BLa, speed and HR, RE and VE, and RE and excess CO_2 (Thomas et al. 1999). Sexes were separated for the Pearson correlation analysis as research has demonstrated that found that male runners had a significantly better RE compared to female runners (Bergh et al, 1991; Daniels & Daniels, 1992)

Chapter 4

Results

Physical and Anthropometric Characteristics

Descriptive and anthropometric characteristics are recorded in table 2.

Table 2. Participant baseline information (mean ± the standard deviation)

Age (years)	20.78 ± 1.84
Sex	7M, 7F
Height (cm)	170.21 ± 9.21
Weight (kg)	62.74 ± 6.20
Resting HR (bpm)	59 ± 7.42
Resting SpO_2	98.29 ± 0.83
Resting Blood Lactate	2.08 ± 0.66
Average Estimated AT MPH	9.5 ± 1.34
Average Estimated AT MPH Male	10.64 ± 0.80
Average Estimated AT MPH Female	8.36 ± 0.48
Average VO_2max ($ml^{-1} \cdot kg^{-1}.min^{-1}$)	56.66 ± 6.60
Average VO_2max ($ml^{-1} \cdot kg^{-1}.min^{-1}$) Male	60.77 ± 5.68
Average VO_2max ($ml^{-1} \cdot kg^{-1}.min^{-1}$) Female	52.54 ± 4.73

M= males, F=Females, cm = Centimeters, kg = Kilogram
HR= Heart Rate, bpm = beats per minute AT = Anaerobic Threshold MPH = Miles per Hour, ml = Milliliters, min = Minute

Analysis using a paired sample t-test revealed that there was no statistical difference between weight, HR, resting SpO_2, and resting BLa, from the first to second testing session.

Validity of Running Economy

A Pearson product-moment correlation coefficient was computed to assess the relationship between RE and HR, BLa and RE, VE and RE, and excess CO_2 and RE. A moderate positive correlation was established in all variables. The results can be viewed in tables 3 and 4.

Table 3. Correlations to Running Economy (Male).

Ventilation	[r =.423, $p < .005$]
Excess CO_2	[r = .629, $p < .005$]
Blood Lactate	[r = .586, $p < .001$]
Heart Rate	[r = .497, $p < .005$]

Table 4. Correlations to Running Economy (Female).

Ventilation	[r = .836, $p <.001$]
Excess CO_2	[r = .814, $p < .001$]
Blood Lactate	[r = .777, $p < .001$]
Heart Rate	[r = .754, $p < .001$]

Additionally, the scatterplots for the correlations of BLa and RE, HR and RE, VE and RE, and excess CO_2 and RE can be viewed below.

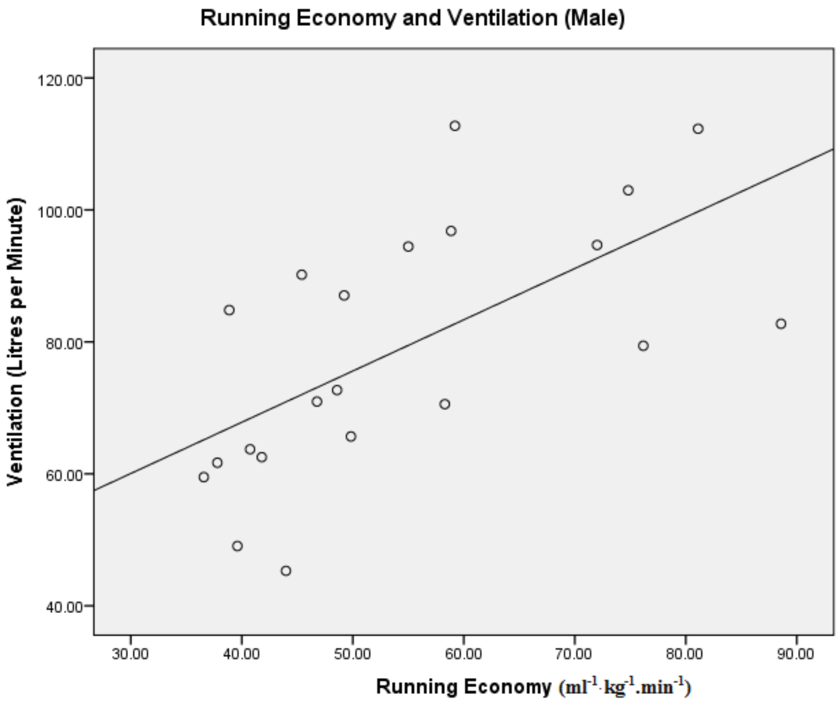

Figure 3: Scatterplot of Running Economy and Ventilation (Male).

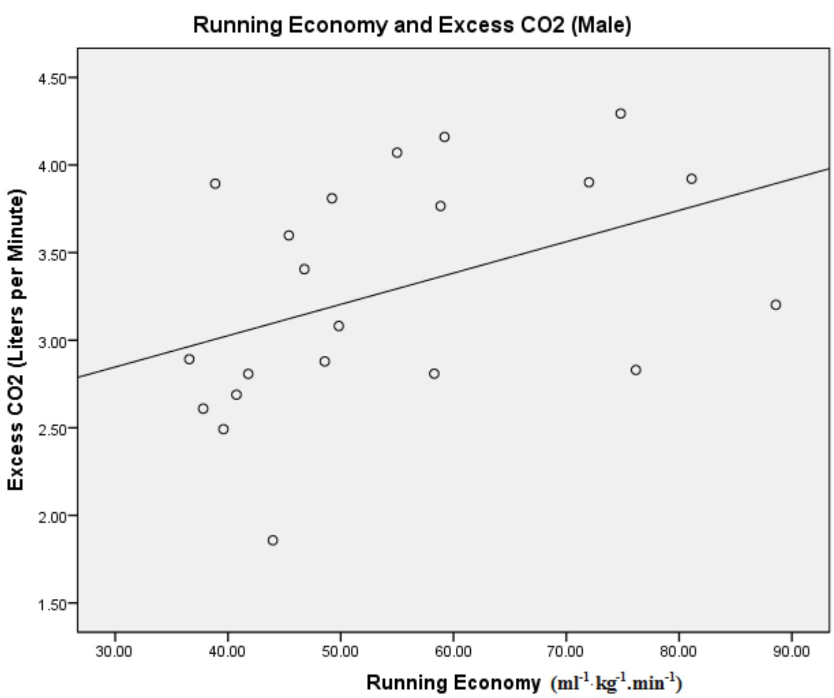

Figure 4: Scatterplot of Running Economy and Excess CO_2 (Male).

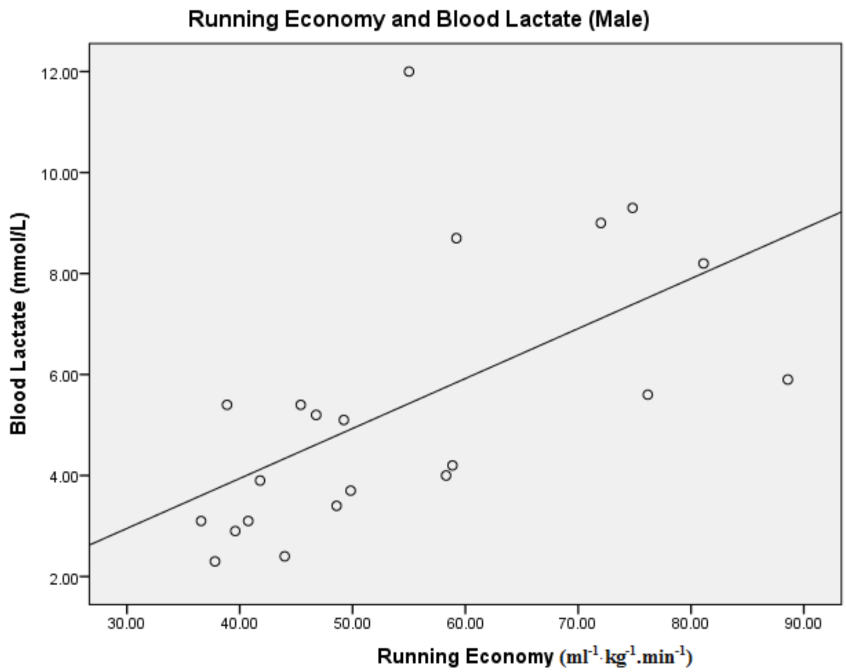

Figure 5: Scatterplot of Running Economy and Blood Lactate (Male).

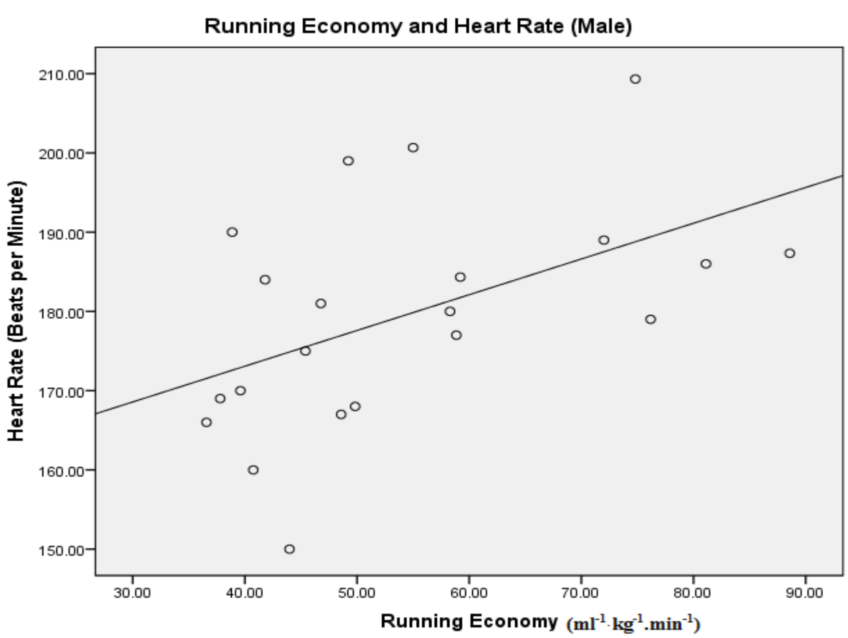

Figure 6: Scatterplot of Running Economy and Heart Rate (Male)

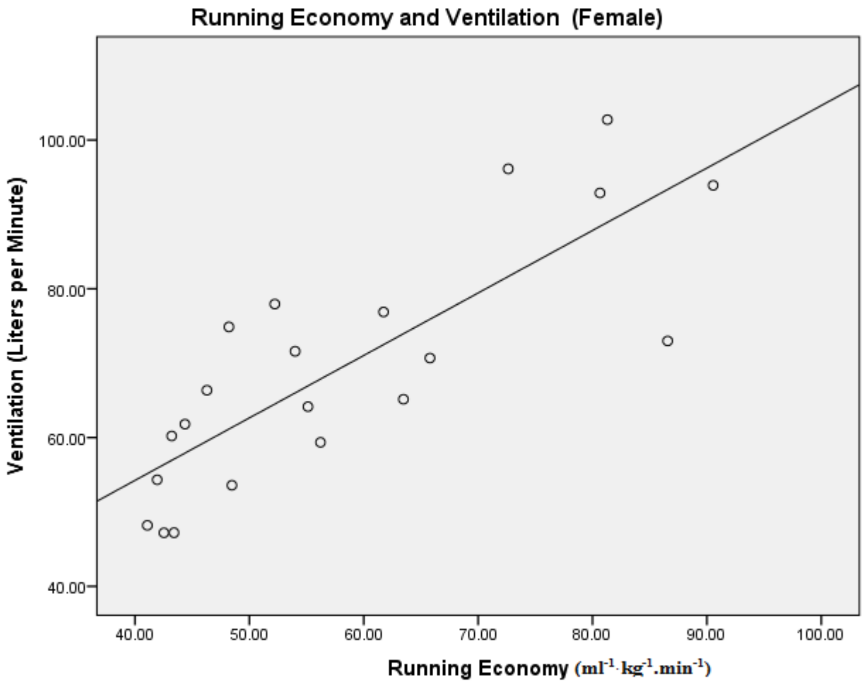

Figure 7: Scatterplot of Running Economy and Ventilation (Female)

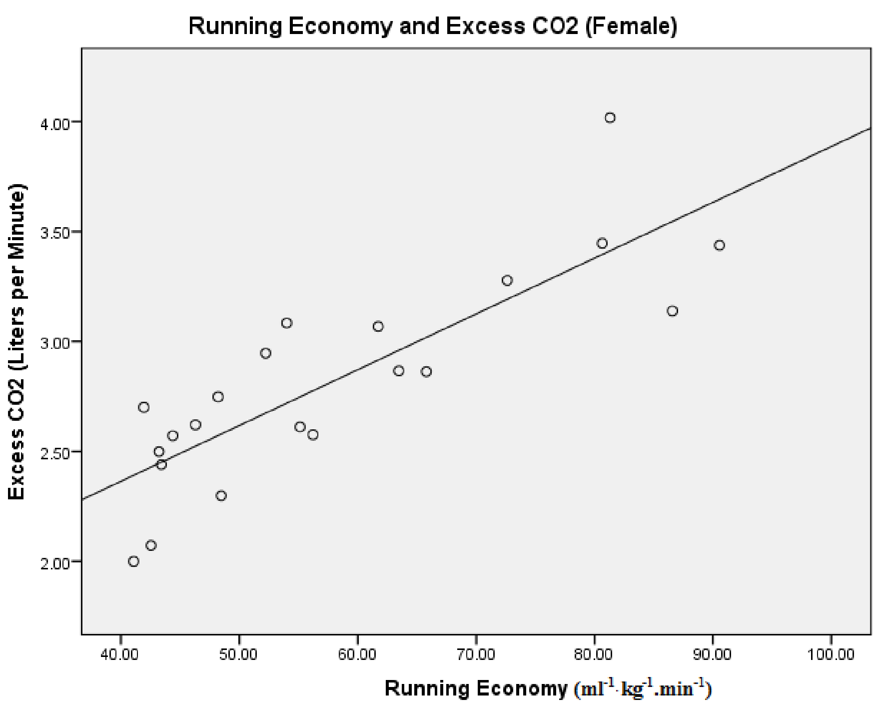

Figure 8: Scatterplot of Running Economy and Excess CO_2 (Female)

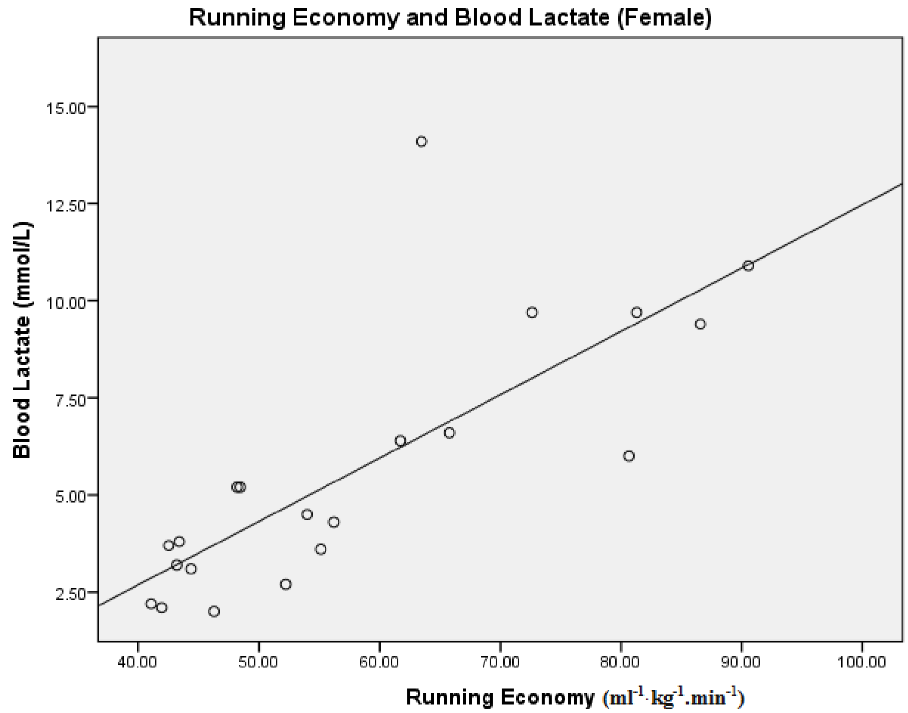

Figure 9: Scatterplot of Running Economy and Blood Lactate (Female)

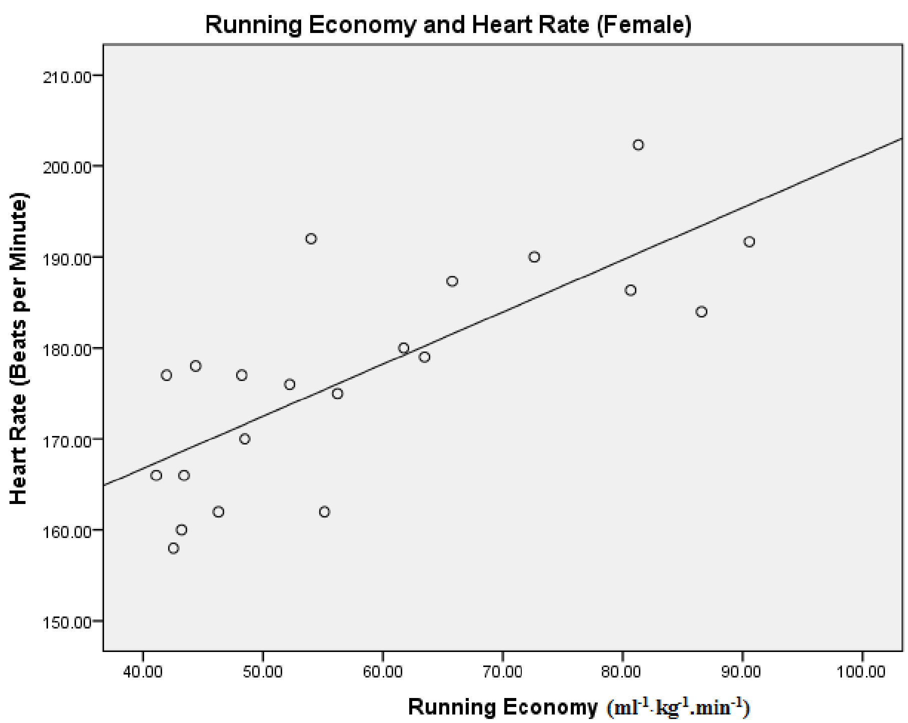

Figure 10: Scatterplot of Running Economy and Heart Rate (Female)

Second Testing Session

Warm-up. All participants warmed-up for 10-minutes at a speed of 5.0 MPH. The average HR during the warm-up was (M = 128, SD = 13.50 beats per minute), indicating that the warm-up was at an appropriate effort (M = 64.0, SD = 3.80 % maximum HR). The average BLa taken in the last minute of the warm-up was (M = 2.40, SD = 1.52 mmol/L), and also helped establish that participants were within normal values.

One mile per hour below anaerobic threshold. The average HR for participants at 1.0 MPH below their AT pace was higher than the warm-up (M = 166, SD = 9.40 beats per minute). The average BLa value was (M = 2.97, SD = 0.67 mmol/L), indicating that some anaerobic effort had increased since the warm-up. Based on the BLa (M = 2.97, SD = 0.67 mmol/L) and the RER values (M = 0.97, SD = 0.03) we can confirm that no participant was at or above their AT pace. The average RE for participants when running 1.0 MPH below AT was (M = 41.70, SD = 3.70 $ml^{-1}\cdot kg^{-1\cdot} min^{-1}$), meaning that more oxygen was required to sustain the pace for this stage, than the warm-up. The mean RPE was taken and recorded (M = 12.30, SD = 1.50).

At anaerobic threshold. The average HR for participants while running at AT pace was higher than the previous three-minute stage (M = 180, SD = 8.51 beats per minute). The difference between the average HR at 1.0 MPH below AT pace (M = 165.5, SD = 9.37 beats per minute) and at AT pace (M = 179.89, SD = 8.51 beats per minute) was statistically significant ($t_{(13)}$ = -13.72, p <.001). Analysis using a paired sample t-test revealed no statistically difference in between HR, HR expressed as % maximum HR, RE, and BLa from test one and test two when running at AT pace. A summary of the results can be viewed in table 5 below.

Table 5. Comparison of Running at Anaerobic Threshold Between test 1 and test 2.

Physiological Measurement	Test 1 VO_2max	Test 2 Running Economy Test	Statistical Value
Heart Rate (BPM)	180 ± 8.0	180 ± 8.52	($t_{(13)}$ = 0.60, p = .276)
Heart Rate (% Maximum)	90.07 ± 3.75	91.87 ± 4.5	($t_{(13)}$ = -1.32, p = .104)
Running Economy ($ml^{-1} \cdot kg^{-1} \cdot km^{-1}$)	53.56 ± 4.62	51.13 ± 6.45	($t_{(13)}$ = 1.13, p = .140)
Blood Lactate (mmol/L)	4.5 ± 0.59	4.6 ± 1.0	($t_{(13)}$ = - 0.26, p = .40)

Additionally, the average RPE was (M = 14.5, SD = 2.0).

One mile per hour above anaerobic threshold. The average HR for participants during the three minutes of running at 1.0 MPH above AT pace was the greatest (M = 190, SD = 8.70 beats per minutes) of the three running intensities. This was also true when expressing the HR as percentage of max HR (M =95.6, SD = 3.50 % max HR). The peak HR following three minutes of running at 1.0 MPH above AT (M = 191, SD = 8.65 beats per minute) was less than the peak HR during the VO_2max test (M = 193, SD = 8.01 beats per minute) and the difference was not statistically significant ($t_{(13)}$ = 1.41, p = .090). The average BLa value following the three minutes of running at 1.0 MPH (M = 8.94, SD of 2.42 mmol/L) was higher than the previous two running speeds. Although the average BLa value was higher post-VO_2max test (M = 10.50, SD = 3.67 mmol/L) the difference between BLa values at the conclusion of both testing session was not statistically different ($t_{(13)}$ = 1.18, p = .13). The average RPE had a mean of 16.07 SD = 2.16. Although the RPE was higher following the VO_2max test (M = 16.85, SD = 1.46) compared to average RPE after the three minutes of running at 1.0 MPH above AT (M = 16.07, SD = 2.16) the differences were not statistically significant ($t_{(13)}$ = 1.30, p = .10).

Cool down. Following the three, three minute intervals, participants performed a 10-minute cool down at the same speed as the warm-up pace (5.0 MPH). The average HR during the cool down (*M* = 146, *SD* = 11.85 beats per minute), was lower than the previous stage. The difference between the HR during the warm-up (*M* = 128, *SD* = 13.50 beats per minute) and cool down (*M* = 146, *SD* = 11.85 beats per minute) was statistically significant ($t_{(13)} = -8.01$, $p <. 001$). Blood lactate was recorded every minute during the cool down. The results revealed that BLa values peaked at minute four of the cool down (*M* = 9.25, *SD* = 5.06 mmol/L). These results are in line with findings with previous studies (Gollnick, Baylyl, & Hodgson 1984; Kulandaivelan et al., 2009). Blood lactate dropped (*M* = 3.73, *SD* = 1.44 mmol/L) after cooling down for 10-minutes.

Chapter 5

Discussion

Running Economy

The evaluation of construct validity typically involves correlations of the measure being examined in regard to variables that are known to possess a relationship to the construct (i.e. BLa and RE) (Bassil & Zabkiewicz, 2014). To the best of our knowledge there have been no studies that have attempted to estimate RE above AT. We therefore proposed that using the short component (three minutes) of the EPOC when added to the oxygen consumption during the anaerobic effort would provide the best rationale and means of estimating RE above AT. The three minutes of EPOC sampled post-exercise was used as it is believed that the short component of EPOC (three to four minutes) represents the oxygen that is required to resynthesize stored ATP and PC, and replenish tissue stores of O_2 (Bahr, 1992; Stainsby & Barclay, 1970). The slow component (three to four minutes or greater), however, it is believed to be responsible for converting lactic acid to glucose in the liver (Powers & Howley 2009).

In order to provide some rationale behind our proposed method of estimating RE above AT, it was estimated that correlations on the variable of RE and the variables of BLa, VE, and excess CO_2 be conducted. Additionally, a correlation on the variable of running speeds and the variables of HR, was also conducted.

Running Economy and BLa were examined using Pearson product-moment correlation, in order to estimate the relationship between RE and BLa values. There was a moderate positive correlation for both male [$r = .586$, $p < .001$] and female participants [$r = .777$, $p < .001$] between the two variables, indicating that as BLa increased, RE decreased. This is in line with previous research as a recent study conducted by Hoff et al., (2016) established that as BLa increased, RE decreased. Typically, athletes begin to lose their running form (one of the factors that affect RE as seen in figure 1) when BLa increases (Hoff et al., 2016). Although the resting BLa levels (M = 2.08, SD = 0.66 mmol/L) were within the normal range, they were slightly on the high side of what is considered normal, as resting BLa levels are typically between 1-2.5 mmo/L (Powers & Howley 2009). This may have been due to a lack of extrinsic controls including diet and menstrual cycle (limitations).

Running economy and HR were examined using a Pearson product-moment correlation. This correlation established a moderate positive correlation for male participants [r = .497, $p <$ .005], and a slightly stronger positive correlation for female participants [r = .754, $p < .001$], meaning that as HR increased RE decreased. These specific correlations were chosen as previous research Pate et al., 1989; Thomas et al., 1995; Thomas et al., 1999; established that as HR increased, RE decreases. In a study that examined 167 habitual distance runners, Pate et al., (1989) used a zero ordered correlation and multiple regression analysis to established a moderate positive correlation ($p < .001$) between an increase in VO_2 ($ml^{-1} \cdot kg^{-1 \cdot} min^{-1}$) and an increase in HR. The study concluded by stating that an improved RE is associated with a lower submaximal HR. However, Bailey and Pate (1991) argued that changes in HR are unlikely to make a significant contribution to changes in RE, inversely improved RE will lower HR at a given workload. The study found that a 20 beat per minute change in HR only increased the VO_2 demand ($ml^{-1} \cdot min^{-1}$) by 8 ($ml^{-1} \cdot min^{-1}$).

Thomas et al. (1999) used a simulated 5,000 m race to establish that an increase in HR, BLa, and VE lead to a decrease in RE. As we were trying to establish construct validity, a Pearson product-moment correlation was conducted on RE and VE. Bailey and Pate (1991), proposed that variations in HR and VE are relatively responsible for changes in RE during both submaximal and maximal exercise efforts (). Thomas et al., (1995) established a correlation [r = 0.79, $p < 0.05$] between changes in VE and changes in oxygen demand during a 5,000m simulated race, using highly trained female runners. Franch et al., (1998) conducted a study using 36 male recreational runners to investigate how different training methods (distance training, long-interval training, and short-interval training) could improve RE. The study reported findings that established a correlation [r = 0.77; $p < 0.001$] between increases in VE and decreases in RE (Franch et al., 1998). It was suggested by that the increased oxygen demand was caused by the increased O_2 demand of breathing (Thomas et al., 1995). Another study conducted by Thomas et al., (1999) set out to determine the effect of a simulated 5,000 m race had on RE, VE, and HR. The study was consistent with other previous findings (Bailey & Pate 1991; Thomas et al., 1995) as RE decreased significantly and VE and HR both increased significantly during the 5,000 m race (Thomas et a., 1999). However, similar to previous findings (Franch et al., 1998; Thomas et al., 1995) the increase in VE was the only variable strongly related to a decrease in RE [r = 0.64, p <0.05]. Therefore, the findings from our study [r =.423, $p < .005$] on male and [r = .836, p <.001] female participants are analogous previous findings that examined RE below AT.

Excess CO_2 was also correlated as there is an established relationship between excess CO_2 and BLa (Wasserman et al., 1986). Excess CO_2 is created as long as the rate of lactic acid production is increasing, as there is additional hydrogen ions to buffer. As the participant's ran above their estimated AT, the production of lactate increased exponentially (Brooks, Fahey, & Baldwin 2005). The result post-exercise, is the removal of lactic acid from the muscle during exercise to the whole body throughout recovery. Thus, buffer action can be measured by the excessive CO_2 expiration (Yano et al. 2005). A moderate correlation [r = .629, $p < .005$] for male and female [r = .814, $p < .001$] participants was established. Revealing that as excess CO_2 increased RE decreased.

These results differ from previous findings (Franch et al., 1998; Thomas et al., 1999), as they found that only VE strongly correlated with a decrease in RE. However, our methodologies differ as participants ran above their estimated AT-pace, and the estimate for RE was also made above AT by analyzing the slow component (three-minutes) of EPOC. As athletes ran above AT, anaerobic metabolites would have exponentially increased (Brooks, Fahey, & Baldwin 2005). As a result, BLa, VE, and excess CO_2, would have been higher (and continuously increasing) when RE was assessed above AT. This may have caused stronger correlations to exists between BLa, VE, and excess CO_2, on RE.

Assessing construct validity often involves correlations on known variables (Bassil & Zabkiewicz, 2014). Previous literature (Bailey & Pate 1991; Franch et al., 1998; Hoff et al., 2016; Thomas et al., 1995; Thomas et al., 1999) suggested that correlations exists between the variables of BLa, ventilation, and excess CO_2 on RE. As a result, correlations were conducted between BLa, ventilation, and excess CO_2, and our proposed means of measuring RE (with three-minutes of EPOC). Moderate correlations were found in between BLa, ventilation, excess CO_2 and RE, with VE having the strongest correlation of the variables. These findings are in line with what previous research (Franch et al., 1998; Thomas et al., 1999) indicated we would expect. Therefore, there is reason to believe that we have established construct validity for our method. Although more research is needed in order to assess the construct validity of this estimate, this means of estimation could have current practical and significant applications. We posit that an athlete and coach may be interested in using our current model as an assessment tool.

Summary

Running Economy was estimated by analyzing the VO_2 ($ml^{-1} \cdot kg^{-1} \cdot km^{-1}$). The quick component value of the EPOC (three-minutes) was added to the sum of oxygen consumption during the last minute of the three-minute stage (one MPH above AT) (Stainsby & Barclay, 1970). We estimated that this would be the best means of creating and measuring construct validity. As correlations are often used to evaluate construct validity, correlations on known variables (BLa, HR, VE, and excess CO_2) were conducted. Ventilation had the strongest relationship to RE. Although some research (Franch et al., 1998;Hoff et al., 2016; Saunders et al., 2004; Thomas et al., 1995; Thomas et al., 1999) have identified relationships between BLa, HR, and ventilation, a lot is still unknown about how these are affected when running above AT. Although further research is required to assess the validity of our estimated means of predicting RE above AT, we believe that this method does make fundamental sense, and could be used as an assessment tool for individual testing.

Overall, this study identified a previously unexplored means of estimating and measuring RE and may provide some theoretical basis for a means of measuring RE above AT. The results suggest that, although, the estimation of RE is not exact, this method is a good starting point. This method could be used to assess intra-individual improvements; however, more research should be conducted before using it as a means of comparison between athletes

Limitations

Limitations of establishing the construct validity of measuring RE by our suggested method include: the speed above AT that was chosen (1.0 MPH above) and the length of time that EPOC was added onto the workload (three minutes). As the only speed above AT examined was 1.0 MPH above, these results, and the amount of EPOC should only be generalized to that pace. Additionally, the warm-up and running at 1.0 MPH below AT, and at AT also contributed to the EPOC. Three minutes of EPOC was chosen as it has been cited as the length of time for the slow component (Stainsby & Barclay, 1970). Although it was out of the scope of this study, it may be worth exploring different speeds above AT, and different lengths of time to sample the EPOC to have a more accurate reflection of measuring RE above AT.

Limitations beyond the measurement of construct validity include the small sample size (seven male and seven female participants), the lack of reliability, and the lack of discriminant validity. Although participants did have some instruction regarding their physical state (i.e. no meal three hours before, no caffeine before, and no high intensity physical work) our largest limitation in this study is that there was no way of ensuring that these guidelines were followed. The lack of control over pre-exercise diet, may have altered BLa results.

Most of the participants run predominantly over-ground as opposed to on a treadmill. Therefore, the use of a treadmill and the variations that exists between treadmill running and over-ground running is another limitation.

Lastly, in order to measure the gases participants had to wear a mask, participants were not typically accustomed to wearing a mask when they ran and this may have altered the results.

Delimitations

This study was delimited to varsity-level male and female participants between the ages of 18-23. This study was also delimited to the pace of 1.0 MPH above AT, and these findings should not be generalized to other paces above AT.

Recommendations for Future Research

Future research should focus on the length that the EPOC is measured, as well as explore the impact that different speeds have on the physiological factors that we have already explored. The significant findings from this study will allow future researchers a starting point to estimate RE above AT. Future research should focus on sampling a larger population, explore the reliability of our proposed method, and could use divergent validity, to ensure that variables that should are known to not possess a relationship with RE do not correlate with this method.

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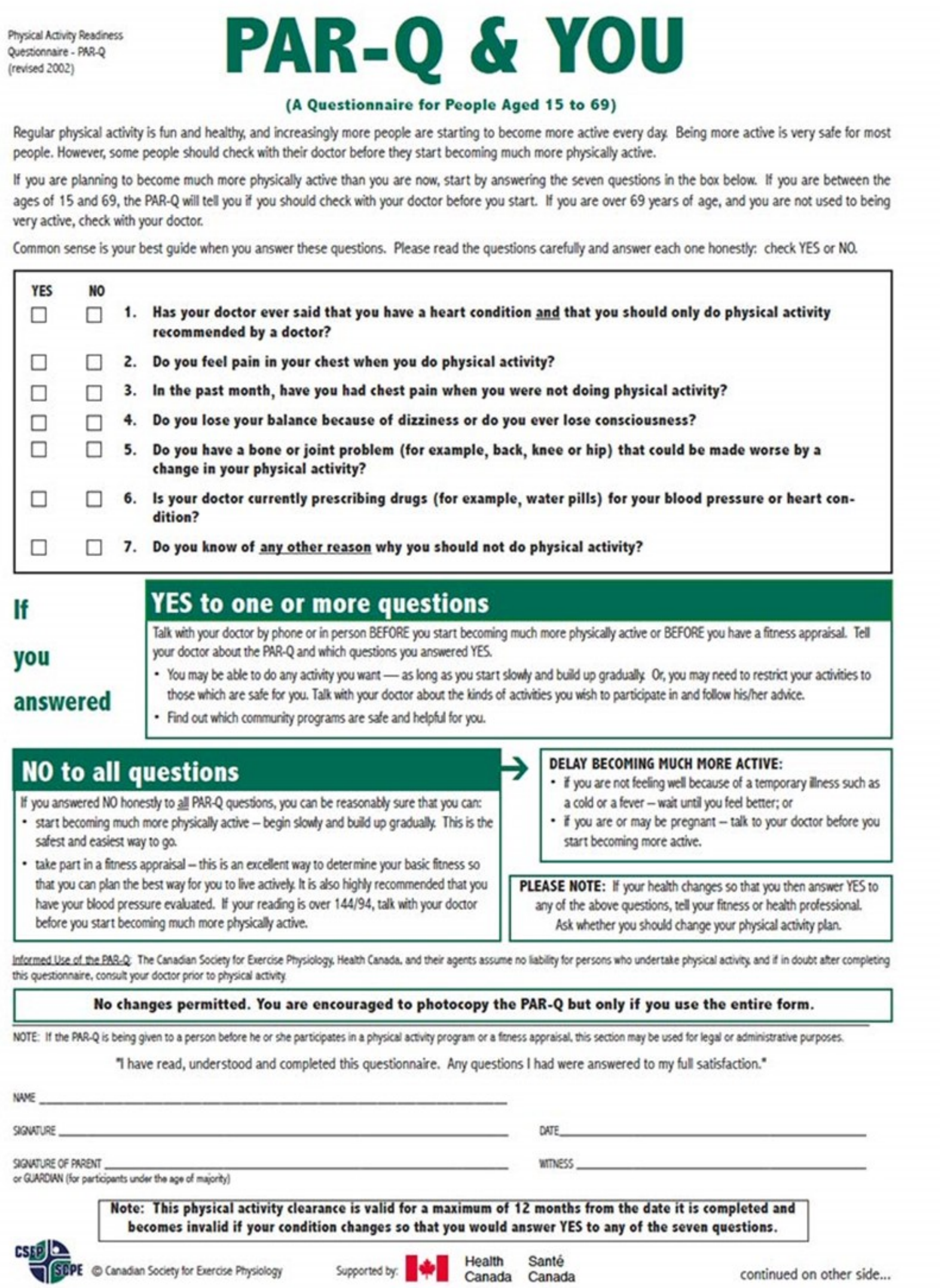
APPENDECIES

Appendix A
Physical Activity Readiness Questionnaire



Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________________ DATE ________________________________

SIGNATURE OF PARENT ________________________________ WITNESS ________________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

Appendix B
Maximal Exertion Testing Pre-Participation Screening Questionnaire

School of Kinesiology, Lakehead University
Maximal Exertion Testing
Pre-participation Screening Questionnaire

The purpose of this form is to ensure that we provide the highest level of care when conducting maximum exertion testing by obtaining specific information regarding your overall health and fitness. This form is completed in addition to a standard ParQ+.

Please read and complete this questionnaire carefully and return it to the researcher(s) prior to the start of the testing.

The information contained in this form is considered confidential and will only be used to pre-screen activity participants.

Personal Information

Name: ________________________________ DOB: _____________________ M F

Height (cm): _________________________ Weight (kg): ______________________

Assess your health status by marking all the true statements.

History
Have you had:
_____ a heart attack
_____ heart surgery
_____ cardiac catheterization
_____ coronary angioplasty (PTCA)
_____ pacemaker/implantable cardiac device
_____ defibrillatory/rhythm disturbance
_____ heart valve disease
_____ heart failure
_____ heart transplantation
_____ congenital heart disease

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in testing or exercise. You may need to use a facility with a **medically qualified staff**.

Symptoms:
_____ You experience chest discomfort with exertion
_____ You experience unreasonable breathlessness
_____ You experience dizziness, fainting, or blackouts
_____ You take heart medications

Other health issues:
_____ You have diabetes
_____ You have asthma or other lung disease

_____ You have burning or cramping sensation in your lower legs
when walking short distances
_____ You have musculoskeletal problems that limit your physical activity
_____ You have concerns about the safety of exercise
_____ You take prescription medication(s)
_____ You are pregnant

Cardiovascular risk factors:
_____ You are a man older than 45 years
_____ You are a woman older than 55 years, have had a hysterectomy,
or are postmenopausal
_____ You smoke, or quit smoking within the previous 6 months
_____ Your blood pressure is >140/90 mm Hg
_____ You do not know your blood pressure
_____ You take blood pressure medication
_____ Your blood cholesterol level is >200 mg/dL
_____ You do not know your cholesterol level
_____ You have a close blood relative who had a heart attack or heart
surgery before age 55 (father or brother) or 65 (mother or sister)
_____ You are physically inactive (i.e., you get <30 minutes of physical
activity on at least 3 days per week
_____ You are >20 pounds overweight

_____ None of the above

You should be able to exercise or participate in testing safely and without consulting your physician or other appropriate health care provider in almost any facility.

Signature:________________________________
Date:_____________________

Adapted from the American College of Sports Medicine (ACSM) and American Heart Association (AHA). ACSM/AHA Joint Position Statement: Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. Med Sci Sports Exerc 1998: 1018; Guidelines for Exercise Testing and Prescription, 7th ed. Baltimore: Lippincott Williams & Wilkins, 2006:25.

Appendix C
First Step Running Questionnaire

FirstStep Running

Running Questionnaire

Name: ________________________ Date: ____________

Address: ____

Phone: (Day) __________________ (Night) ______________

Date of Birth: ___________ Height: ________ Weight: ________

How long have you been running? ____________

Why are you interested in running?

- ❑ Fitness
- ❑ Weight Loss
- ❑ Recreation
- ❑ Stress Relief
- ❑ Social
- ❑ Recreational Racing
- ❑ Competitive Racing
- ❑ Other ____________________

How many kilometers do you run a week? __________

What surfaces do you run on?

- ❑ Sidewalk/Asphalt
- ❑ Grass
- ❑ Trails
- ❑ Gravel
- ❑ Treadmill
- ❑ Other: __________________

Have you used a treadmill before? Yes / No

Please break down your weekly kilometers (ie how many kilometers to long runs, tempo, hills, speed work, etc.)

Do you participate in any other forms of activity/ exercise? Please list all activities and their frequencies (including stretching and strength training).

Have you ever had a running injury. Please describe.

How old are your current running shoes? ______________________________

How often do you change them? ______________________________

Do you or have you had any of the following:

- ❑ Surgeries
- ❑ Hospitalized
- ❑ Epilepsy
- ❑ Heart conditions
- ❑ Lung conditions
- ❑ Osteoporosis
- ❑ Arthritis
- ❑ Allergies
- ❑ Diabetes
- ❑ Currently pregnant
- ❑ Muscle cramping
- ❑ Dizziness/ Vertigo
- ❑ Headache
- ❑ Concussion/ Head injuries
- ❑ Double vision
- ❑ Ringing in the Ears
- ❑ Other
- ❑ High blood pressure
- ❑ High cholesterol
- ❑ Other: ________________

Please explain.

____

____

____

Are you currently taking any medications? Please explain.

____

____

Have you ever passed out during or after exercise? Yes / No

Have you ever been dizzy during or after exercise? Yes / No

Have you ever had chest pain during or after exercise? Yes / No

Have you ever had high blood pressure? Yes / No

Have you ever had a heart murmur? Yes / No

Have you ever had racing of your heart or skipped heartbeats? Yes / No

What are your running goals?

____

____

Do you feel there are any barriers to achieving these goals?

____

____

What do you hope to get out of this assessment?

- ❑ Improve running efficiency
- ❑ Rehabilitate injury
- ❑ Prevent injuries
- ❑ Correct muscle imbalances
- ❑ Improve running performance
- ❑ Other: ____________________

Please explain.

____

____

Appendix D
Ethics Approval Letter

Lakehead UNIVERSITY

Research Ethics Board
t: (807) 343-8283
research@lakeheadu.ca

January 26, 2016

Principal Investigator: Dr. Ian Newhouse
Co-Investigator: Vineet Johnson
Student Investigators: Kevin Tree, Sebastian Biebel
Research Assistant: David Thompson
School of Kinesiology
Lakehead University
955 Oliver Road
Thunder Bay, ON P7B 5E1

Dear Dr. Newhouse and research team:

Re: REB Project #: 110 15-16 / Romeo File No: 1464997
Granting Agency: N/A
Granting Agency Project #: N/A

On behalf of the Research Ethics Board, I am pleased to grant ethical approval to your research project titled, "Exploring a Potential Mean of Measuring Running Economy Above Anaerobic Threshold".

Ethics approval is valid until January 26, 2017. Please submit a Request for Renewal to the Office of Research Services via the Romeo Research Portal by December 26, 2016 if your research involving human participants will continue for longer than one year. A Final Report must be submitted promptly upon completion of the project. Access the Romeo Research Portal by logging into myInfo at:

https://erpwp2.lakeheadu.ca/

During the course of the study, any modifications to the protocol or forms must not be initiated without prior written approval from the REB. You must promptly notify the REB of any adverse events that may occur.

Best wishes for a successful research project.

Sincerely,

LChambers

Dr. Lori Chambers
Chair, Research Ethics Board

/scw

Appendix E
Biosafety Approval Letter

Lakehead
UNIVERSITY

OFFICE OF HUMAN RESOURCES
t: (807) 343-8334 f: (807) 346-7701
e: human.resources@lakeheadu.ca

February 10, 2016

Mr. Vineet Johnson
Health and Behavioural Sciences\Kinesiology

Dear Mr. Johnson:

RE: Application "The effect of running above anaerobic threshold on running economy in varsity cross country runners" - Romeo Certification File #1464940

I am pleased to inform you that the Lakehead University Biosafety Committee has approved your application titled "The effect of running above anaerobic threshold on running economy in varsity cross country runners"; - Romeo Certification File #1464940. Biosafety approval has been granted until **September 01, 2016** (expiry date of biosafety protocols 1462024). In order to continue working with biohazardous materials after September 01, 2016, a renewal request for this project accompanied by a full biosafety protocol application must be submitted to the Lakehead University Biosafety Committee.

In accordance with biosafety policy, any personnel wishing to participate in this project, must have completed training prior to working with any biohazardous materials.

Best wishes for a successful research year.

Sincerely,

T. Moore.

Tiffany Moore
Biosafety Officer

343-8806

cc. Office of Research
Dr. S. Lees, Biosafety Committee Chair

Appendix F
Recruitment Letter

Blank 2015,

Dear potential participant,

I would like to extend an invitation to participate in a research study being conducted by me, Sebastian Diebel, a graduate student in the School of Kinesiology at Lakehead University School of Kinesiology, supervised by Dr. Ian Newhouse. You are being asked to participate because you are a current member of the Lakehead Cross Country and Track Team and are a trained aerobic athlete.

The purpose of this study is to determine the effect of running above lactate threshold on running economy in trained varsity cross-country and track runners.

All participants will be asked to attend 2 individual testing sessions which will be approximately 60- 75 minutes each in duration. Prior to each session, your height, body mass, resting heart rate, resting blood pressure, and a baseline lactate sample will be recorded. The blood lactate sample will involve a small prick at the end of your finger, with a drop of blood being drawn. You will then warm up for a total of 15 minutes, consisting of running 10 minutes on a treadmill at a warm up pace. Following that a 5-minute stretching routine that is common to running will take place. Testing will start after the warm up is complete.

The first testing sessions will consist of running a VO_2max test until you are unable to continue or it is unsafe to do so. The VO_2max test involves running on the treadmill at progressively harder workloads every minute until exhaustion (usually around 12 minutes). The second testing session will commence at 1 mph below your calculated anaerobic threshold. You will be asked to run for 5 minutes below, at, and 1 mph above your anaerobic threshold.

During data collection, your heart rate will be monitored and recorded, and a blood sample will be taken immediately after the completion of each of the workloads and following the VO_2max tests at intervals of 0,1,2,3,4, and 5 minutes. Similarly during the second test you will be asked to provide blood lactate measures every minute during the running and at intervals of 0,1,2,3,4, and 5 minutes post treadmill test.

You will also be asked to record your perceived intensity level for each VO_2max test on a Rating of Perceived Exertion scale of 6-20. When the testing session has been completed, you will cool down for 10 minutes on the treadmill and then do static stretching for 5 minutes.

You will be asked to not eat a substantial meal within 3 hours before the test, abstain from alcohol 24 hours before the test, abstain from coffee, tea, or other caffeine sources for at least 1 hour before the test and to not train or do high intensity physical work on the day of the testing. If any of the above guidelines have not been adhered to on the day of testing, you will be asked to return on another day.

Potential risks of participating in this study include, but are not limited to, elevated heart rate, minor sprains and/or strains, shortness of breath, and the possibility of contusions. Given that the testing is of high intensity, you may experience muscle soreness in the days following the test.

Participation in this study is completely voluntary; you have the right to withdraw at any time without penalty, and all information will be strictly confidential, at no time will you be asked to verbalize your results to the other participants present. Only the researchers will have access to the recorded data and personal information, and no identifiable characteristics will be used in the final report. Data will be securely stored in Dr. Newhouse's office SB1017, School of Kinesiology, Lakehead University for a period of 5 years. Your results from this study will be available to you upon request following the completion of the study. If you have any questions please feel free to contact me at 632-6261 or at sdiebel@lakeheadu.ca. This research has been approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 343-8283 or swright@lakeheadu.ca.

Thank you,

Sebastian Diebel, MSc (c), ☎(807) 632-6261
•sdiebel@lakeheadu.ca

Dr. Ian Newhouse, Graduate Supervisor
•ian.newhouse@lakeheadu.ca

Mr. Vineet Johnson, Committee Member
•vineet.johnson@lakeheadu.ca

Appendix G
Letter to Lakehead University Cross-Country and Team Track Coach

Lakehead University Cross-Country and Track Team Coach,

I would like to extend an invitation to have Lakehead University athletes participate in a research study being conducted by me, Sebastian Diebel, a graduate student in the School of Kinesiology at Lakehead University School of Kinesiology, supervised by Dr. Ian Newhouse. The purpose of this study is to determine the effect of running above lactate threshold on running economy in trained varsity cross-country and track runners.

All participants will be asked to attend 2 individual testing sessions which will be approximately 60- 75 minutes each in duration. Prior to each session, the height, body mass, resting heart rate, resting blood pressure, and a baseline lactate sample from each participant will be recorded. Participants will then warm up for a total of 15 minutes, consisting of running 10 minutes on a treadmill at a warm up pace. Following that a 5-minute stretching routine that is common to running will take place. Testing will start after the warm up is complete.

The first testing sessions will consist of running a VO_2max test until participants are unable to continue or it is unsafe to do so. The VO_2max test involves running on the treadmill at progressively harder workloads every minute until exhaustion (usually around 12 minutes). The second testing session will commence at 1 mph below the participants calculated anaerobic threshold. Participants will be asked to run for 5 minutes below, at, and 1 mph above their anaerobic threshold.

During data collection, participants heart rate will be monitored and recorded, and a blood sample will be taken immediately after the completion of each of the workloads and following the VO_2max tests at intervals of 0,1,2,3,4, and 5 minutes. Similarly, during the second test participants will be asked to provide blood lactate measures every minute during the running and at intervals of 0, 1,2,3,4, and 5 minutes post treadmill test.

Participants will also be asked to record their perceived intensity level for each VO_2max test on a Rating of Perceived Exertion scale of 6-20. When the testing session has been completed, participants will cool down for 10 minutes on the treadmill and then do static stretching for 5 minutes.

Participants will be asked to not eat a substantial meal within 3 hours before the test, abstain from alcohol 24 hours before the test, abstain from coffee, tea, or other caffeine sources for at least 1 hour before the test and to not train or do high intensity physical work on the day of the testing. If any of the above guidelines have not been adhered to on the day of testing, the participant will be asked to return on another day.

Potential risks for participants in this study include, but are not limited to, elevated heart rate, minor sprains and/or strains, shortness of breath, and the possibility of contusions. Given that the testing is of high intensity, participants may experience muscle soreness in the days following the test.

Participation in this study from the Lakehead University athletes is completely voluntary; they will have the right to withdraw at any time without penalty, and all information will be strictly confidential, at no time will they be asked to verbalize their results to the other participants present. Only the researchers will have access to the recorded data and personal information, and no identifiable characteristics will be used in the final report. Data will be securely stored in Dr. Newhouse's office SB1017, School of Kinesiology, Lakehead University for a period of 5 years. The results from this study will be available to participants upon request following the completion of the study. If you have any questions please feel free to contact me at 632-6261 or at sdiebel@lakeheadu.ca. This research has been approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team, please contact Sue Wright at the Research Ethics Board at 343-8283 or swright@lakeheadu.ca.

Thank you,

Sebastian Diebel, MSc (c), ☎(807) 632-6261
•sdiebel@lakeheadu.ca

Dr. Ian Newhouse, Graduate Supervisor
•ian.newhouse@lakeheadu.ca

Mr. Vineet Johnson, Committee Member
•vineet.johnson@lakeheadu.ca

Appendix H
VO_2max Protocol

Time (Minutes)	Male	Female
1	7	6
2	7.5	6.5
3	8	7
4	8.5	7.5
5	9	8
6	9.5	8.5
7	10	9
8	10.5	9.5
9	11.0	10
10	11.5	10.5

The initial treadmill speed was set at 7.0 MPH for male and 6.0 MPH for female participants and increased 0.5 MPH every minute. The treadmill grade remained horizontal until the subject completed three workloads past the respiratory exchange ratio (expired CO_2/inspired O_2) value of 1.0 or a blood lactate level equal to or greater than 4.0 mmol/L was achieved. At that time, the speed remained constant and the grade of the treadmill increased 2.0 % every minute. Participants continued to run until exhaustion or it was unsafe to do so.

Appendix I
Borg Rating of Perceived Exertion Scale (Borg, 1982)

BORG SCALE
Rating of Perceived Exertion

6	
7	Very very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Vary hard
18	
19	Very very hard
20	

Appendix J
Blood Lactate Sampling Procedure

This procedure will be supervised by a Registered Nurse. The researchers and study participants will be required to clean their hands with disinfecting gel before they enter and exit the lab.

Methods
The lab will be conducted in the Exercise Physiology Laboratory (SB 1025). Informed consent will be obtained, and a Physical Activity Readiness Questionnaire (Par-Q) will be completed.
The procedures for taking blood samples are as follows:

Equipment

-Lactate measurement device with test strips
-Latex gloves, lab coat
-Lancets
-Disinfecting wipe
-Sterile gauze pad
-Biohazard waste disposal container
-Sharps container

Sampling Procedures

The participant will sign the informed consent, agreeing to the lactometer test prior to performing the lactometer test.

The test will be performed by a Registered Nurse who is also a certified phlebotomist.

Each of the investigators will wear a lab coat and nitrile gloves.

Directions for the lactometer test are as follows:

- Clean your finger thoroughly with an alcohol swab as demonstrated to you by the investigator.
- Wait until the alcohol dries completely.
- Prick the chosen site on the finger with the lancing device. The skin will be pierced with a single-use lancet (on the fingertip), and a small drop of blood will accumulate on the surface of the skin. This drop of blood will be wiped with a sterile gauze pad. The lancet will be put into the sharps container, and the pad will be put into the biohazard waste disposal container.
- Put a little drop of blood on the test strip.
- Insert the test strip into the lactometer device.
- In seconds, the blood lactate level will appear on the screen.
- Once completed, please clean your skin with a cotton swab and apply a band aid over the pricked skin.

At the completion of the testing on one participant, the investigators will remove the pair of latex gloves and put them into the biohazard waste disposal container and put on a new second pair of gloves. At the completion of the testing session, the gloves will be removed and the hands will be washed using soap and hot water.

Appendix K
Maximal Exercise Assessment Checklist

Maximal Exercise Assessment Checklist (*Nov. 2007 – updated Oct. 2014)*

(Complete for all Max. Assessments – in-class demonstrations, labs and research – file with Par-Q)

Preparation	√
Protocol presented to the Risk Management Committee for review & recommendation (includes termination guidelines).	
Supervisor is recognized by the Risk Management Committee as having competence with maximal testing.	
Supervisor certified with Standard First Aid and CPR.	
Supervisor will be on-site for all max. assessment activity.	
Approved physician on-site for max. assessment with **high risk participants.**	
Equipment and facility prepared and inspected for safety of operation.	
Exercise protocol and termination guidelines discussed by the supervisor with all those involved in the actual assessment prior to commencing.	
Screening & Risk Stratification	
Par-Q+ & Screening Stratification Questionnaire reviewed and completed with low risk populations.	
Par-MedX completed by physician for moderate to high risk populations.	
All screening records to be maintained in the School of Kinesiology for seven years.	
Assessment	
Exercise protocol verbally reviewed with participant and posted in clear view.	
Exercise termination guidelines reviewed and posted in clear view.	
Informed consent signed by participant.	
Post-exercise vital signs monitored and recorded.	
Completed screening tools and assessment records filed in the Kinesiology office.	
Incidents/accidents promptly addressed, report form completed and filed with the Kinesiology office.	

Name of Participant: ____(print)

____(sign)

Health Card #: ____

Date of Assessment: ____

Supervisor ____(print)

____(sign)

Witness: ____(print\sign)

Appendix L
Informed Consent

School of Kinesiology
807-632-6261
sdiebel@lakeheadu.ca

I, ____ (PLEASE PRINT), consent to participate in this study. I am aware that the purpose is to measure the effects of running above the lactate threshold on running economy in varsity cross country runners. Using VO_2max, heart rate, respiratory exchange ratio, pulmonary ventilation, lactate accumulation, excess post oxygen consumption and rating of perceived exertion.

I understand that I will be asked to attend two 60-75 minute sessions. Prior to the first session, I will be asked to sign and complete a consent form, Par-Q form, Maximal Exertion Testing Pre-Participation Screening Questionnaire, and a First Step Running Questionnaire.

I understand that I will be asked to perform a maximal (VO_2max) test and a secondary test treadmill test that consists of 5 minutes of running under anaerobic threshold, 5 minutes at anaerobic threshold and 5 minutes above anaerobic threshold.

I understand that I will complete a 15-minute warm-up including dynamic stretching before the testing, a cool down following the testing, and will wear a heart rate monitor with a chest strap. I will also be asked to offer blood samples using a Lactate Scout blood lactate analyzer. I am aware that height, body mass, and age will be recorded.

I understand that on the day of testing, I will be asked to not eat a substantial meal three hours before the test, abstain from alcohol 24 hours before the test, abstain from coffee, tea, or other caffeine sources for one hour before the test and do not train or do high intensity physical work 24-hours before the testing. If any of the above guidelines have not been adhered to on the day of testing, I understand I will be asked to return on another day.

I understand that participation in this study is entirely voluntary, and I am able to withdraw from this study at any time without penalty. I understand that all information that I provide will remain confidential. Data will be securely stored in Dr. Ian Newhouse's office SB1017, School of Kinesiology, Lakehead University for a period of 5 years.

I have been informed of the tests that I am asked to perform and I am aware that with all physical activity and sports, some risk of injury exists. I understand that risks in participating in this study may include, but are not limited to; elevated heart rate, sprains, strains, contusions and muscle soreness. I accept all of these risks by participating in this study.

Signature of Participant and Date

Do you consent to have your information sent to you?

Yes ____ No____

Signature of Witness and Date:

Appendix M
Data Collection Sheet

Preparation	
1. Equipment/Facility is in working condition and ready for use	
2. Supervisor is Present	
3. Researchers and Supervisor have been briefed on testing and have been assigned a position	
Participant Screening/Introductions	
1. Researchers and Supervisor welcome and introduce themselves to the participant	
2. Participants have received, read, and understand recruitment letter. Have read, understood, and signed Informed consent form	
3. PAR-Q, Maximal Exertion, FirstStep running questionnaire have been completed and signed	
Baseline Measures	
1. Height/Weight taken and recorded	
2. Resting Blood Pressure taken	
3. Patient is instructed to lie in a supine position for 5minutes. Patient commences quiet rest with fingertip oximeter in correct position and working	
4. Resting hear rate and oxygen saturation recorded after 5 minutes of quiet rest	
Warm-up	
1. Participant is briefed on warm-up procedure	
2. Participant warms-up on the treadmill for 10 min at 5mph	
3. Mask prepared for participant	
Pre-VO_2	
1. Heart rate monitor is put on the participant's chest in correct position	
2. Fingertip oximeter is put on participants left hand	
3. Mask is correctly placed over participants nose and mouth such that there is no leaking from any side of the mask and It is comfortable on participant	
4. Participant is re-briefed on blood sampling procedure prior to testing commencing	
5. Researchers are in safety positions and know their role in the event of a participant falling	
6. - Incline/speed is controlled (1person) - heart rate taken (1 person) - oxygen saturation (1 person) - metabolic cart being monitored (1 person) - Values recorded (HR, O_2 sat., RER) (1 person) - Time of test (start/finish) recorded (1 person)	

7. Someone records the Speed when the AT is established.	
. Mask is hooked up to the metabolic cart via tube. Make sure the tube is suspended correctly so that it does not interfere with participant during test, or become disconnected at any point	
VO_2 test (follow protocol)	
1. Heart rate/oxygen saturation is taken at minute 0 of test and as protocol states thereafter	
2. Encouragement is given by researchers	
3. Stop button is pressed at the end of the test or when participant can no longer continue safely	
Post-test	
1. Participant begins 10min cool-down at 5 MPH, relatively soon after test has been completed	
2. Heart rate and oxygen saturation is continuously monitored throughout the cool down. Values are recorded once every minute	
3. Blood pressure is taken and participant is safe to leave after it has returned to a value ≤ 144and heart rate is ≤ 99 beats per minute.	