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Editorial

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Monitoring of Core Body Temperature During Exertional Heat Illnesses Emergencies

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This editorial is to promote the use of rectal thermometer devices during an exertional heat illnesses (EHI) emergency. With today's technology, there are hand-held electronic monitors in the market, that allow the athletic trainer on the field, to insert the probe end, and continually monitor the core body temperature while cooling efforts are attempted, and emergency medical services (EMS) is activated. Standard glass thermometers are useful, but a digital readout would be constant. Time is an issue, seconds count. The athletic trainer is taught to recognize the signs and symptoms of EHI, which may include syncope, profuse sweating, irritability, confusion, dizziness, loss of balance.[1-7] Unfortunately, these signs and symptoms may also present themselves with head trauma/concussion.[1-5] The ONLY confirmation of an EHI is the elevated core body temperature of >40 °C (>104 °F).[1] Oral, tympanic, axillary or temporal methods of taking the temperature using external thermometers are not as reliable as the rectal thermometer in assessing elevated core body temperature.[3] During a suspected EHI, the athletic trainer should remove the athlete from direct sunlight and seek a cooler, shaded area or go indoors to an air-conditioned room.[1-5] The athlete's core body temperature needs to be assessed, and this would include removal of clothing and equipment to not only cool the body, but to gain access to the rectal area.[4-7] This can be done on the field or once you have moved the athlete indoors. Time is of the essences, the sooner you can establish a core body temperature readings, the sooner you have an EHI diagnosis and can begin (cooling) treatment and activate EMS.[1,5] Cooling *via* cold-water immersion up to the neck is the most effective way to treat an athlete with EHI, and having the (rectal) core body temperature monitoring device inserted, the athletic trainer can continue to monitor the core body temperature. Your goal is to lower core body temperature to <38 °C (<102 °F) and this should be done within 30 minutes of the athlete collapsing.[1-5] Precautions should be taken not to overcool the body, and monitoring the core body temperature throughout the EHI event, should prevent this.[1] If an immersion tub is not available, partial-body immersion using small tubs or pools can be used in addition to wet ice towels over the entire body. Using a hand-held monitor can continue even after EMS has arrived and is transporting the athlete to the hospital emergency room (ER).

In my opinion (based solely on personal conversations), we have athletic trainers that do not feel comfortable administering a rectal thermometer to a patient. According to a published letter from S. Raab, PhD, athletic trainer certified (ATC), in May 2014, to the editors of National Athletic Trainers' Association (NATA) News,[8] he gave reasons why we should not be doing rectal temperatures during an EHI. His rationale included his being uncomfortable treating an underage minor of the opposite gender. In addition, he cited other reasons including letting ER personnel perform this function. This generated a rebuttal letter from KC. Miller, PhD, ATC, et al published in the July NATA News, Letter to the Editor.[9] It should be noted that Miller et al are leaders in EHI research. In their Letter to the Editor, they discussed point by point their response to the Raab's letter. Their views were backed by scientific evidence as to WHY, during an EHI incident, we should be monitoring core body temperature using a rectal thermometer.[1,8] In my opinion, I agree with Miller et al, and in an EHI incident, time is of the essence, seconds count and you need to access the effectiveness of your cooling treatment during the incident, up to arrival of EMS and during transport.

Over the past 4 years, there have been NATA position statements, educational recom-

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mendations and articles written discussing the use of rectal thermometers during an EHIs emergencies. Given these past articles and an official NATA position statement, it is in the best interest of monitoring the core body temperature throughout the EHI incident, from the initial diagnosis to the arrival at the Emergency Care facility.

Regarding the uncomfortable nature of this topic, how do we solve this dilemma? First we need to discuss some common facts: Exertional heat illnesses can be prevented and if accurately diagnosed, effectively treated. Lives can be saved. Second, time is of the essence, the athlete needs to be properly assessed and a core body temperature needs to be taken. Third, once EHI is confirmed, the athlete needs to be cooled immediately. Fourth, cooling cannot wait for EMS to arrive, minutes count. As Adams noted, "cool first, transport second; the clock is ticking".[2] Immediate measures need to be taken to immerse in a cooling tub or a modified method (tarp) of cooling immersion so the core body temperature can be reduced.[10] Again, the effectiveness of any cooling that is done during an EHI is a rectal thermometer reading throughout the emergency. According to the NATA Position Statement on exertional heat illness, the use of a rectal thermometer should be utilized on any suspected EHI emergency.[1] In further review of the literature, Mazerolle et al,[4] Casa etal,[3] and Stearns et al,[11] all documented employing the use of rectal thermometers and obtaining readings to monitor core body temperature in EHI emergencies. Based on this review of literature, we need to make rectal thermometers or electronic hand-held rectal thermometers a part of our medical kits. In addition, a review of your institutional emergency action plan needs to address the issue of EHIs and use of rectal thermometers or electronic hand-held monitoring devices. Lastly, and this should be at the front of your process, as education should occur BEFORE an EHI incident. Education of parents, school administrators, school boards and athletes needs to be done on why this procedure is necessary, why it can be life-saving and how important it is to monitor the core body temperature throughout the EHI incident. We also need to educate ourselves, so we are comfortable with the administration of thermometers, either hand-held electronic devices or just old fashion glass thermometers.[1,5] We need to educate, so we can remove the stigma of inserting a diagnostic probe into the rectal region.

CONFLICTS OF INTEREST

The author acknowledges there is no conflict of interest.

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Research

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Agreement Between Methods to Estimate Residual Lung Volume: A Methodological Investigation

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ABSTRACT

Introduction: The determination of residual lung volume are technically challenging and can involve rather elaborate techniques. However, due to the complex nature of measurement protocols, a number of studies have attempted to use alternative estimation techniques, including application of regression equations following spirometry measurement, panting manoeuvres and general predictive equations. With such extensive measures, it is difficult to reach a consensus where all residual lung volume measures are in agreement, hence the aim of this methodological investigation.

Methods: Twenty two participants (n=10 male and n=12 female) were recruited from the University of Gloucestershire, undergraduate programmes. All participants were over 18 years of age and all were free from disease, illness or injury ($\overline{\chi}\pm s$; age=20.5±1.7 years, body mass=68.7±1.5 kg and stretched stature=172.0±8.3 cm). Three estimations of residual lung volume were carried out by participants, a '*spirometry*' method (*via* forced vital capacity), a '*panting*' method (*via* the air displacement plethysmograph (BOD POD®)) and a general '*prediction*' method (based on age, gender, ethnicity and stature predictive equation to estimate whole body density (D_b)). Data analysis was conducted to establish the linear relationship and agreement between the three estimation methods by constructing scatter plots showing deviation from the line of identity and by applying the 95% limits of agreement (LoA) method to quantify the bias, random variation and heteroscedasticity.

Results: Results indicated that linear relationships were evident from the scatter plots, but this was expected given they were measuring the same variable. Further analysis with limits of agreement indicated that there was a bias of 0.13, 0.17 and 0.04 l for the panting, spirometry and prediction estimation techniques and limits of agreement of 0.47 to -0.21, 0.45 to -0.11 and 0.23 to -0.15 L respectively.

Conclusion: The spirometry technique demonstrated a more accurate estimation of residual lung volume when compared to panting and prediction techniques, in addition, as spirometry uses standard (and the simplest) techniques to determine lung volumes, and is the most widely used method within research determining D_b from hydrostatic weighing, it was concluded that the spirometry method would be the measurement approach of choice for determination of residual lung volume.

KEY WORDS: Residual lung volume; Whole body density; Spirometry; Methods: Measurement error.

ABBREVIATIONS: LoA: Limits of Agreement; VC: Vital Capacity; FEV^1: Forced Expiratory Volume in one second; MMEF: Maximum Mid-Expiratory Flow; FVC: Forced Vital Capacity; BTPS: Body Temperature and Pressure Saturated.

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INTRODUCTION

The determination of lung volume are technically challenging and involves rather elaborate techniques that vary from: (i) helium dilution, where a closed-circuit spirometer apparatus is filled with a mixture of gas in the lung with a known volume of gas containing helium and oxygen; (ii) nitrogen (N_2) washout, where the technique is based on the participant inhales 100% O_2 and exhales through a one-way value measuring N_2 content and volume; (iii) body plethysmography, where changes in lung volumes that accompany compression or decompression of the gas in the lungs during respiratory manoeuvres, and (iv) using imaging techniques such as conventional radiographs, computerised tomography, magnetic resonance imaging, where images at the time of lung inflation can provide estimates of lung volumes.[1-3]

Lung volumes derived from conventional direct measures are usually based on the volumes within the outlines of the thoracic cage and the volume of tissues, as well as the lung gas volume.[3,4] Indirect methods following maximal exhalation using spirometry have been commonly used as an less technically challenging estimation of residual lung volume.[1,4-8] Typical measures with spirometry include: (i) vital capacity (VC) and its two subdivisions (a) slow vital capacity (SVC) which is the maximal amount of air exhaled steadily from full inspiration to maximal expiration and is not time dependent and (b) forced vital capacity, which involves the volume of lungs from full inspiration to forced maximal expiration. (ii) forced expiratory volume in one second (FEV^1) where the volume of air is expelled in the first second of a forced expiration (iii) forced expiratory ratio (FER %) is the percentage of FVC expelled in the first second of a forced expiration ((FEV^1/FVC) x100) (iv) forced expiratory flow between 25-75% (FEF 25-75%) (also known as the maximum mid-expiratory flow (MMEF)) this is the expiratory flow rate in the middle part of a forced expiration.

There is an assumed value of 0.9-1.6 L in a normal healthy adult male[6,8]; however, any assumptions in the determination of residual lung volume may lead to errors in body volume as large as ±0.5 L for a given individual, thus leading to an underestimation of D_b.[10] A study by Wanger et al[2] compared various direct and indirect methods and results indicated that body plethysmography yielded higher results than helium dilution, nitrogen (N_2) washout and spirometry. Therefore, with such extensive measures, evidence suggests that it is still difficult to reach a consensus where all lung volume measures are in agreement.[1,7] Therefore, the aim of this investigation was to investigate the agreement of the estimation of residual lung volume from three possible approaches. These included, a '*spirometry*' method (*via* spirometry),[1,3,9] application of regression equations following '*panting*' method (*via* the air displacement plethysmograph (BOD POD®))[4,6,8,9] and a general '*prediction*' method (based on age, gender, ethnicity and stature[10-13] to estimate D_b.

METHODS

Twenty two participants (n=10 male and n=12 female) were recruited from the University of Gloucestershire, undergraduate programmes. All participants were over 18 years of age and all were free from disease, illness or injury ($\bar{x}\pm s$; age=20.5±1.7 years, body mass =68.7±1.5 kg and stretched stature=172.0±8.3 cm). Participants completed a Health Questionnaire and this information was used in processing a flow diagram to determine whether the participants were eligible to take part in the testing. If eligible, the participants were requested to give written informed consent and they understood their rights to withdraw. In order to carry out three approaches to estimate residual lung volume, the following data processes were undertaken by all participants.

The '*Spirometry*' Method

All participants sat in an upright position and applied a nose clip, whilst holding the Spirometer (Micro Medical Micro Loop Spirometer model 3535) breathing tube in their dominant hand. A rate of breathing for the participant was called by the rater which comprised of three cycles of inhalation and exhalation. On the third cycle call, the rater asked the participant to take a large inhalation and then a maximal exhalation that was blown out through the tube. Each participant was given three attempts to obtain their best forced vital capacity (FVC) value. The greatest FVC value was corrected for body temperature and pressure saturated (BTPS) that was determined by using a correction table.[14] Finally the corrected FVC value was transferred to the spirometry equation dependent upon gender of each participant:

$$LV_{spir} = FEV\ (BTPS)\ (L) \times 0.24 \quad \text{- (males)}$$

$$LV_{spir} = FEV\ (BTPS)\ (L) \times 0.28 \quad \text{- (females)}$$

Where:
LV=lung volume; FVC=Forced vital capacity; BTPS=body temperature and pressure saturated[14]

The '*Panting*' Method

All participants followed a measurement protocol, with step by step instructions given on the BOD POD® system computer. Participants were asked to apply the nose clip and hat and enter the BOD POD® and sit with an erect posture with their hands folded on their laps and feet placed on the floor of the chamber. The chamber door was then closed and sealed. During the test, participants were instructed to put the breathing tube (that was connected to the BOD POD®) in mouth and follow the cadence displayed on the screen by breathing in and out of the tube. Between the 4th and 6th breath a message alert appeared on the screen '*prepare to puff*'. During exhalation the breathing tube closed for 2 s and coincided with the message '*puff, puff, puff*' on the screen. Participants were required to puff gently three times whilst maintaining a tight seal between the mouth and tube. At the end of the 3rd puff the measurement was completed (after ≈ 3-5 minutes) derivation of lung volume (l) was provided *via* the BOD POD® system computer, using the following equation:

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$$(LV_{pant} = (TV/2\ (L) + FRC\ (L)$$

Where: LV=lung volume; TV=tidal volume; FRC=functional residual capacity (Life Measurement Inc.,)[15]

The '*Prediction*' Method

In order to calculate the predicted residual lung volume participants age (y) and stretched statue (cm) were required. Once obtained, the data was then transferred to the equation derived by Crapo et al[1] and a single value recorded:

LV_{pred} (L)=0.410x(stature (cm))-(0.210 x age (years))-26.31
Where: LV=lung volume (Crapo et al[11])

Data analysis involved the construction of scatter plots to determine the linear relationship between the three estimation methods of spirometry, panting and prediction from all participants and by applying the 95% limits of agreement (LoA) method to quantify the bias, random variation and heteroscedasticity. These analyses provided illustrative examples to see the deviation from the line of identity and to determine whether significant differences (under-reporting) were evident between the three estimation methods.

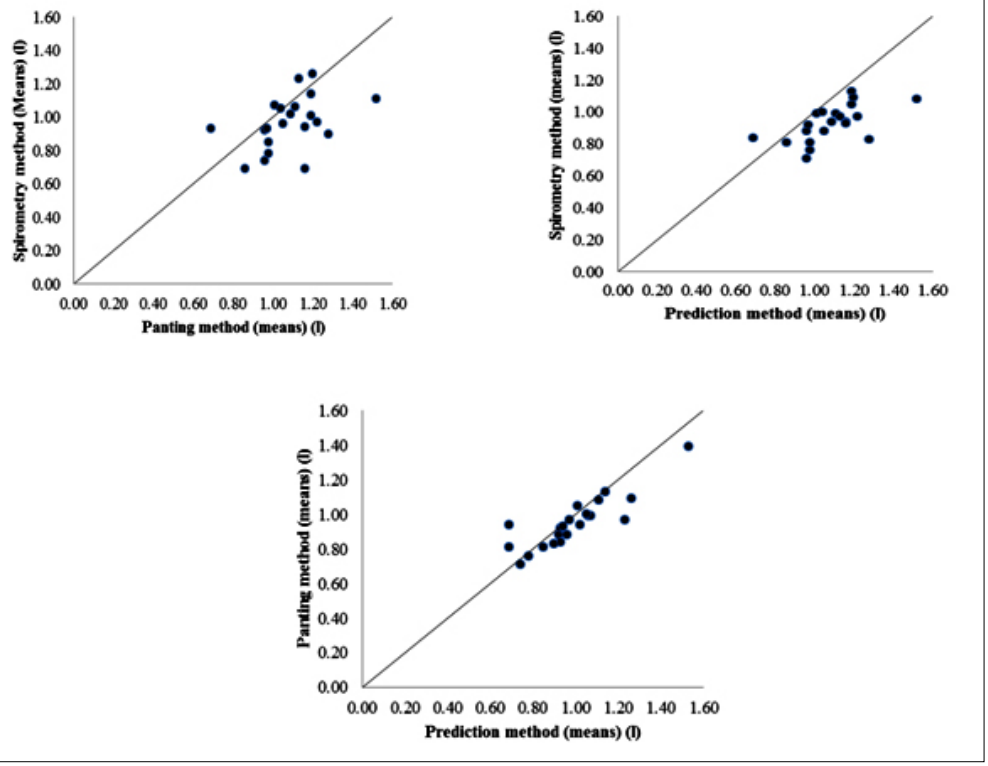
RESULTS

Three scatter plots are provided for illustrative purposes to demonstrate the linear relationship between the separate measures of residual lung volumes as shown in Figure 1. Linear relationships between the three residual lung volume measures were found, but closer inspection of Figure 1 did show some deviation from the line of identity, particularly with the spirometry – panting and spirometry–prediction method. Although, it is important to note this linear relationship was expected given that they are measuring the same variable.

Due to the expected linear relationships found in Figure 1, further analytical investigations were needed to determine the agreement between the three different approaches to estimate residual lung volume. Bias, random variation and 95% limits of agreement approaches were then applied, and illustrated in Figure 2.

Evidence from Figure 2 indicated there was a bias of 0.13, 0.17 and 0.04 l for the panting, spirometry and prediction estimation techniques and limits of agreement of 0.47 to -0.21, 0.45 to -0.11 and 0.23 to -0.15 L respectively. To quantify these findings, if for example, a new participant (not one from the *n*=22 sample) measured 1.2 L for residual lung volume there is a 95% probability that when measured using the spirometry, panting, and prediction estimation techniques, estimation of residual lung volume can be estimated as low as 1.2 L-0.47=0.73 L to as high as 1.2 L+0.21=1.41 L; 1.2 L-0.45=0.75 L to as high as 1.2 L+0.11=1.31 L and 1.2 L-0.23=0.97 L to as high as 1.2 L+0.15=1.35 L respectively. Overall these findings suggest that the spirometry technique demonstrated a more accurate estima-

Figure 1: Comparison between Spirometry and Panting Methods; Spirometry and Prediction Methods and Panting and Prediction Methods for Estimating: Lung Volumes (l).



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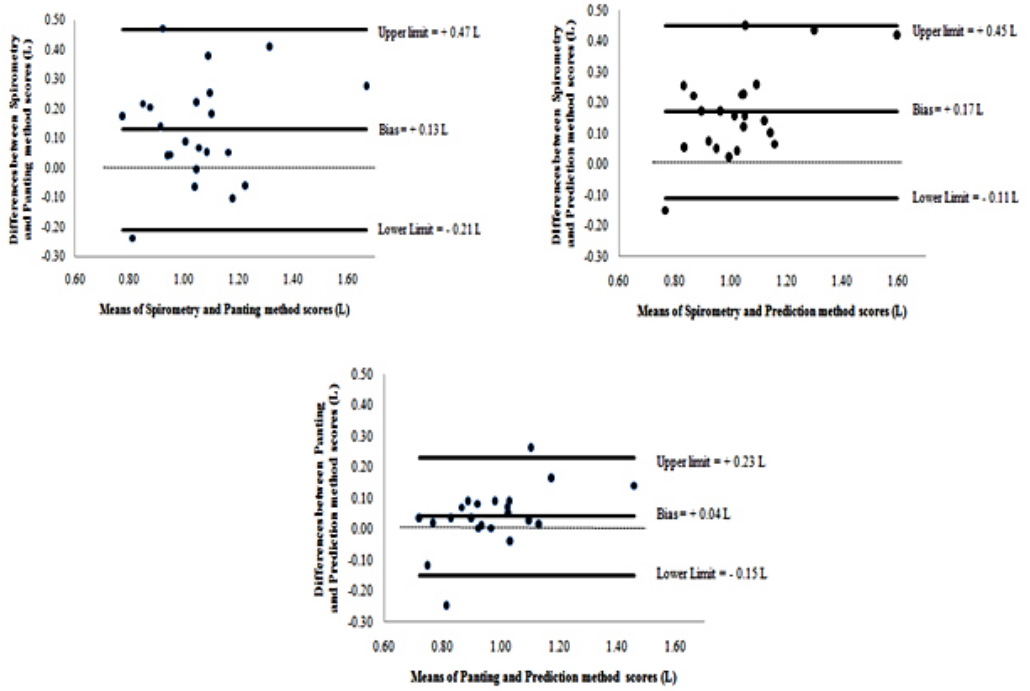

Figure 2: Bland and Altman Plot Showing Bias and 95% Limits of Agreement for the Spirometry and Panting Methods (Note: Direction of Bias [Panting–Spirometry]); Spirometry and Prediction Methods (note: Direction of Bias [Prediction–Spirometry]) and Panting and Prediction Methods (note: Direction of Bias [Prediction–Panting]) for Lung Volumes (l).

tion of residual lung volume by 0.29 L when compared to panting and prediction estimation techniques. Whilst it is important to recognise that these differences, albeit small, they could potentially overestimate residual lung volumes and consequently underestimate D_b.

CONCLUSIONS

Results from this investigation showed linear relationships between the spirometry and panting methods and the spirometry and prediction methods for estimating residual lung volumes; however, a stronger relationship between the panting and the prediction methods (Figure 2). It is important to note that these linear relationships were expected given they were measuring the same variable. In relation to limits of agreement data analyses, the bias was modest (0.17 L at worst), with the spirometry method giving lower values than both the predicted and the panting methods respectively. The best agreement (negligible bias and lowest limits of agreement) was between the panting and the prediction methods (0.04±0.19 L), although these methods provided higher values of residual lung volume. These findings suggest that the spirometry technique demonstrated a more accurate estimation of residual lung volume when compared to panting and prediction techniques.

Practical implications were also considered to reinforce the argument for the best measure to estimate residual lung volume. For instance, the panting method requires the use of the BOD POD®, whilst undertaking an unusual and sometimes problematic breathing technique and the prediction method is reliant on regression equations without practically measuring any lung volumes. Whereas the spirometry method uses standard (and the simplest) techniques to determine lung volumes and is considered the most widely used method within research determining D_b from hydrostatic weighing.[1,6,8,16] Research has suggested that studies that used alternative methods to spirometry such as panting and prediction methods should be treated with caution, as they are likely to overestimate residual lung volumes and consequently underestimate D_b.[1,16] Thereby within body composition analyses, it is important to recognise the impact this underestimation could have on a participants D_b if residual lung volume is not reliably measured. It was therefore concluded that given the absence of a criteria measure, the spirometry method would be the obvious measurement approach of choice for determination of residual lung volume for future research.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Effects of Dietary Nitrate Supplementation Over Four Weeks on Maximum Oxygen Consumption in Recreational Runners: A Pilot Study

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ABSTRACT

Introduction: Nutritional aids to improve exercise performance have become popular. One of the newest is dietary nitrate, often administered as a drink known as beetroot juice (BR). This has led many athletes, both elite and recreational, to consume BR prior to competition or physical activity. However, the results have been inconsistent and indicate that several factors need to be considered.

Purpose: The purpose of this study was to evaluate the effects of BR consumption or placebo in two groups of recreational runners running a minimum of 15 miles per week.

Methods: Ten women and three men volunteered to participate in this four week study. Each participant completed a maximal oxygen consumption test (VO_{2max}). Data from the exercise test used for analysis included VO_{2max}, maximum heart rate (HR_{max}) and time of the maximal exercise test (T). Participants were then randomly assigned to either the Beetroot Juice Group (BRJ, n=7) or the Placebo Group (P, n=6). Each participant was given 16-four ounce bottles prefilled with the juice for their respective group. Participants were instructed to consume the juice 30 min prior to their exercise bouts (4/week) over the next four weeks, then return for follow-up testing.

Results: Thirteen subjects completed the four week study (BRJ=7; P=6) and returned for post-testing. Statistical analyses were conducted using a two factor, repeated measures ANOVA to determine differences between the two groups for the initial and final VO_{2max} tests, as well as within the groups from pre- to post-testing after the four weeks. The initial values for VO_{2max}, (P=44.7±5.0 ml/kg/min; BRJ=47.6±8.4 ml/kg/min) HR_{max} (P=174.7±15.6 bpm; BRJ=171.7±11.2 bpm), and T (P=12:06±1:26 min:sec; BRJ=12:22±0:08 min:sec) were not significantly different between the two groups (p>0.05). At the conclusion of the four week study, the results for the post maximal exercise test were VO_{2max} (P=45.0±6.3 ml/kg/min; BRJ=49.3±8.8 ml/kg/min), HR_{max} (P=171.7±16.6 bpm; BRJ=172.3±8.7 bpm), and T (P=12:06±1.36 min:sec; BRJ=12.43±0.07 min:sec) were not significantly different (p>0.05). However, there was a significant increase in the average time of the VO_{2max} test for the BRJ of 20.7 sec (p=0.02). None of the other variables measured over the four week training session were significantly different (p>0.05).

Conclusion: These results indicate that dietary nitrate supplementation (16 oz/week) did not increase exercise performance with the exception of a significant increase in the average time of the VO_{2max} test for the BRJ group. This may be the result of learning to run on the treadmill or a reduction in the O_2 cost of exercise due to possible ergogenic effects of dietary nitrate supplementation. These findings may be further attributed to the varying training regimens, diets, and time of consumption.

KEY WORDS: Beetroot juice; Maximum oxygen uptake; Dietary nitrate; Nitric oxide.

ABBREVIATIONS: RPE: Rated Perceived Exertion; HR_{max}: maximum Heart Rate; VO_{2max}: maximum oxygen uptake; NO: Nitric Oxide; NOS: Nitric Oxide Synthase; NO_3^-: Nitrate; NO_2^-: Nitrite; BR: Beetroot juice; BRJ: Beetroot Juice Group; O_2: Oxygen.

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INTRODUCTION

Elite athletes, their coaches as well as exercise physiologists and sports scientists are constantly looking for ways to enhance performance. But even recreational "athletes" who may simply want to finish a race[1] are often seeking ways to improve training and recovery. Nutritional aids have become popular and one of the newest ones is dietary nitrate, often administered as a drink known as beetroot juice (BR). The high nitrate concentration of beetroot juice is thought to serve as a precursor for nitric oxide (NO) production. This would be an additional source to the endogenous pathway during which L-arginine is oxidized in a reaction catalyzed by the nitric oxide synthase (NOS) family.[2] Nitrate (NO_3^-) is found in all vegetables and is especially abundant in leafy greens and beetroot.[3] After ingestion the NO_3^- is reduced to nitrite (NO_2^-) by anaerobic bacteria in the oral cavity by the action of nitrate reductase enzymes,[4] then to nitric oxide (NO) in the stomach.[5] It is well established that nitrate or BR consumption can significantly increase plasma nitrite concentration (both as a substrate for and a biomarker of nitric oxide production).[6]

Nitric oxide (NO) is an important signaling molecule in many physiological processes including muscle contractility, mitochondrial respiration and biogenesis, and the regulation of tissue blood flow.[7] Physiological mechanisms for NO_2^- reduction are facilitated by hypoxic conditions; therefore, NO as a vasodilator is produced in the parts of the muscle that are consuming or in need of more oxygen (O_2).[8]

These findings suggest that supplementation with NO_3^- to increase the bioavailability of NO to influence muscle function should improve exercise performance, primarily in aerobic metabolism.[9] This has led many athletes, both elite and recreational, to consume BR prior to competition in an effort to improve performance.[10]

However, the results have been inconsistent and indicate that several factors need to be considered. These include the duration of supplementation (acute *vs*. more chronic), the dose of nitrate consumed, the training status of the participants tested, habitual nitrate intake, and the duration and intensity of the exercise.[10] Well-trained individuals will typically have higher baseline plasma nitrite and nitrate values than those who are less physically active.[11] If athletes are already consuming a greater amount of dietary nitrates then the addition of a nitrate supplement may have no effect.[12] Therefore, the purpose of this study was to evaluate the effects of BR consumption or a placebo (Sugar-free Cherry-flavored Kool-Aid) in two groups of recreational runners who had not been consuming beetroot juice as part of their training regimen.

METHODS

Participants

Approval for this study was obtained from the University's Institutional Review Board (IRB) and 13 participants (males and females) gave written informed consent to participate. The inclusion criteria required that participants be willing to consume their given drink four times per week for four weeks and that they were willing to run a minimum of 15 miles per week. Participants were excluded if they were unwilling to consume the drink provided, were allergic to the placebo or beetroot juice or were unable to run a minimum of 15 miles/week for the next four weeks. The 13 participants who completed the program (10 females and 3 males) had an average age of 41.9±14.9 years.

Maximal Exercise Test

The participants reported to the Exercise Science Research Laboratory for an initial maximal exercise test. Participants were asked to dress in exercise clothes for the initial assessment and asked not to eat for 2-3 hours before testing. Water prior to exercise test was allowed and recommended. Upon arriving at the lab, a Polar heart rate monitor was strapped around the chest and the headgear fitted to hold the Rudolph mouthpiece in place during the Bruce protocol. A Parvo TrueOne® 2400 Metabolic Cart was used to assess the oxygen consumption on a breath-by-breath basis while the participants walked/ran on a Quinton Q Stress treadmill. Maximal oxygen uptake (VO_{2max}) and maximum heart rate (HR_{max}) were assessed along with the duration (T) of the maximal exercise test for each participant.

Supplement

Upon completion of the VO_{2max} test, the 13 participants were randomly assigned to either the placebo (sugar-free Cherry-flavored Kool Aid, n=6) group or to the group that would consume beetroot (BRJ, n=7) juice. Lakewood Farms PURE Beet Juice containing organic beetroot juice and organic lemon juice (1%) was used. Each participant was given 16 prefilled bottles and instructed to consume 4 bottles per week. Each bottle contained 4 oz (120 ml) of either the placebo (P) or BRJ and the participants were instructed to consume one bottle 15-30 min prior to their workout, at least 3 times per week. The 4th bottle could be consumed prior to a 4th workout or sometime during the week if they routinely worked out 3 days per week. Participants were then asked to continue their regular exercise routine, minimum of 15 miles/week and to log the day the liquid was consumed along with the distance in miles they ran. The 4 oz or 120 ml of concentrated BRJ contained 9.7 mmol NO_3^-.

At the completion of four weeks each participant returned to the Exercise Science Research Laboratory and repeated the maximal exercise test utilizing the Bruce protocol. No additional beetroot juice was consumed prior to the final exercise test.

Statistical Analysis

Analyses were conducted using SPSS (Version 23.0; IBM SPSS Inc., Chicago, IL, USA) to conduct a two factor repeated mea-

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sures ANOVA with one within subjects factor time (pre, post) and one between subjects factor group (placebo, beetroot juice). The following variables were analyzed: VO_{2max}, HR_{max}, and duration of maximal exercise test (in minutes and seconds). The alpha level for significance was set at $p \leq 0.05$.

RESULTS

Thirteen participants completed the study (P, n=6; BRJ, n=7). The demographic information for the two groups is provided in Table 1. Differences in the variables measured during the initial maximal oxygen consumption test are found in Table 2 and those same variables measured at the end of the four weeks of consuming either the sugar-free Kool-Aid (P) or the beetroot juice (BRJ) are found in Table 3. There were no significant differences found in the initial maximal exercise test results for VO_{2max}, the HR_{max}, or the time (T) of the maximal exercise test between the two groups at the beginning of training session or for the final maximal exercise results ($p>0.05$). However, analysis of the changes within each group, over the course of the four weeks, indicated a significant increase ($p=0.02$) in the time of the VO_{2max} test (20.7±16.9 sec) for the BRJ group (Table 5) but not for the other variables for the BRJ or P groups (Table 4; $p>0.05$).

The changes (Δ) for each variable were also analyzed using ANOVA to determine if the two groups changed differently over the four week time period (Table 6). However, there were no significant interactions between the two groups for any of the variables ($p>0.05$).

From the exercise logs it was determined that the runners for the BRJ averaged 22.5±9.7 miles/wk while the P group averaged 21.7±5.6 miles/wk.

Table 1: Subject Demographics.

P (n=6)	Mean	SD	BRJ (n=7)	Mean	SD	*p* values
Age (yrs)	44.7	18.7		39.6	12.0	0.56
Height (cm)	166.1	4.54		170.4	7.3	0.24
Weight (kg)	62.4	6.2		60.6	16.2	0.80

Table 2: Pre 4 Week Training Test Results – Between Groups.

	Placebo (n=8)		Beet Juice (n=8)		
	Mean	SD	Mean	SD	*p* values
VO_{2max} mL/kg/min	44.7	5.0	47.6	8.4	0.47
HR_{max} bpm	174.6	15.6	171.7	11.2	0.69
Time Max Min:sec	12:06	1:26	12:22	0.08	0.64

Table 3: POST 4 Week Training Test Results – Between Groups.

	Placebo (n=6)		Beet Juice (n=7)		
	Mean	SD	Mean	SD	*p* values
VO_{2max} mL/kg/min	45.0	6.3	49.3	8.8	0.34
HR_{max} bpm	171.7	16.6	172.3	8.7	0.93
Time Max Min:sec	12:06	1:36	12:43	0.07	0.52

Table 4: Within Group (Placebo).

	Pre		Post		
	Mean	SD	Mean	SD	*p* values
VO_{2max} mL/kg/min	44.7	5.0	45.0	6.3	0.82
HR_{max} bpm	174.6	15.6	171.7	16.6	0.11
Time Max Min:sec	12:06	1:26	12:06	1.36	0.30

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Table 5: Within Group (Beetroot Juice).

	Pre		Post		
	Mean	**SD**	**Mean**	**SD**	***p* values**
VO_{2max} mL/kg/min	47.63	8.4	49.3	8.8	0.21
HR_{max} bpm	171.7	11.2	172.3	8.7	0.85
Time Max Min:sec	12:22	0.08	12:43	0.07	0.02

Table 6: 4-Week Changes (Δ).

	Placebo (n = 6)		Beet Juice (n=7)		
	Mean	**SD**	**Mean**	**SD**	***p*-values**
Δ VO_{2max} mL/kg/min	0.3	3.1	1.7	3.0	0.44
Δ HR_{max} bpm	-3.0	3.8	0.6	7.5	0.32
Δ Time Max sec	8.33	18.18	20.71	16.9	0.23

DISCUSSION

The results of our study of comparing the effects of BRJ to a placebo over the course of four weeks did not show any significant improvement in VO_{2max} or HR_{max}. However, the BRJ group had an increase in the time of exercise (20.7±16.9 sec) that was significantly different (p=0.02) from the increase of the P group (8.3±18.1 sec). Bailey et al[13] hypothesized that dietary BR supplementation would reduce the O_2 cost of moderate-intensity exercise and increase exercise tolerance. Their definition of increased exercise tolerance was assessed as an increase in the "time to task failure" and results showed an increased time to task failure of 16%, suggesting that dietary nitrate supplementation might enhance high intensity exercise performance. Our results appear to be in agreement that the beetroot juice supplementation increased the time to exhaustion (task failure) during the maximal exercise test for the BRJ as there were no significant increases in either the VO_{2max} and HR_{max}.

There are other reasons that may account for this lack of change in exercise performance. Participants were asked to continue their individual training regimens and only asked to complete a minimum number of miles/week (15 miles) and to consume the BR 15-30 min prior to at least three workouts per week. The 4th bottle could be consumed prior to a workout or at anytime during the week. No instruction was given as to the time of day of their workouts. For those who prefer to conduct their workouts in the morning, it is possible that the BR may have been consumed following the use of an antibacterial mouthwash. An early study showed that the increase in plasma nitrite after consuming dietary nitrates is the result of nitrate accumulation in saliva and reduction to nitrite by oral bacteria. The activity of oral bacteria is stopped by antibacterial mouthwash activity thus attenuating any rise in plasma nitrate.[6]

Training status has also been shown to have an impact on whether dietary nitrate supplementation will improve performance. Endurance-trained athletes have higher eNOS (endothelial NO synthase situated in the capillary walls) and nNOS (neuronal NO synthase situated in muscle fibers) activity[14,15] which will likely lead to an increased NO production *via* the L-arginine pathway and may explain why the majority of studies with trained individuals (VO_{2max}>60 ml/kg/min) report no effects on exercise performance[16,17]. The runners in our study withVO_{2max}-levels in the mid-40s's range (45 ml/kg/min P; 46 ml/kg/min BR) would not be considered "elite" and it was anticipated that there would be some benefit from consumption of the dietary nitrate supplementation.

The dosage or mmol/L of dietary nitrates consumed has been shown to impact exercise performance. Our dosage of 9.7 mmol NO_3^- per dose was similar to that found to elicit responses in exercise performance to acute consumption (8.4 mmol).[12] However, when the effects of long-term consumption of dietary supplementation (15 days) was investigated, participants consumed the supplement on a daily basis.[18] Our study extended the time over which the supplement was consumed (4 weeks) however, the total days of consumption would have been less (12 days *vs*. 15 days). It would seem that four doses per week of even a high concentration of BR were not sufficient to improve exercise performance.

Due to the large daily energy expenditure of athletes, it is likely that these individuals are already consuming greater amounts of dietary nitrates suggesting that additional intake may not be effective.[10] Upon questioning participants as to their daily vegetable intake, the majority indicated that they did not consume the daily recommended vegetable servings and that it was closer to 1-3 servings/day. One subject in the BRJ stated that they consumed a vegetarian diet, and, in fact, her VO_{2max} was the only one to show a decrease within the BRJ group. In a previous investigation, supplementation of dietary ingestion of nitrate ap-

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peared to have actually reduced VO_{2max}.[19]

CONCLUSION

Four weeks of consumption of a high dose of dietary nitrate supplementation did not improve maximal exercise performance when compared to a placebo. Despite a high concentration of the dietary nitrate, four doses per week did not appear to be sufficient to impact maximal exercise. Another recommendation that should be made is for the timing of the consumption of the BR prior to exercise. In a previous study, the acute effects of BR consumption on plasma [NO_2^-] were assessed and it was found that levels peaked 3 h post-ingestion and remained close to peak values until 5 h post-ingestion.[20] Consumption by our participants 30 min prior to exercise may have resulted in the plasma levels peaking when they had completed their exercise bout. Future studies should include charting dietary intake to determine the nitrate consumption from the daily diet to determine the total intake along with any supplementation.

The one significant finding of an increased time of exercise by BRJ group (p=0.02) supports the findings by Bailey et al,[13] while their study found a considerable reduction in the O_2 cost during submaximal cycle exercise, it was also suggested that increased dietary NO_3^- intake has the potential to enhance exercise tolerance during high intensity exercise performance. Therefore, the possible ergogenic benefit of dietary nitrate supplementation should also be an area of further research.[13]

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AUTHORS CONTRIBUTIONS

All authors have contributed to the data collection and writing of this manuscript.

CONFLICTS OF INTEREST

The authors indicate that they have no conflicts of interest to declare.

PARTICIPANTS CONSENT

The Informed Consent Document was approved by the Institutional Review Board for the Protection of Human Subjects at our University.

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Research

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Physiological Response to Cyclocross Racing

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ABSTRACT

Introduction: Cyclocross is a growing discipline of cycling that combines elements of both mountain biking and road racing. The purpose of the study was to describe the intensity of the sport of cyclocross using competition heart rate (HR) and blood lactate [La^-] data.
Methods: Eight experienced cyclocross racers participated in both a laboratory graded exercise test and a cyclocross race. During laboratory testing, peak oxygen consumption ($\dot{V}O_{2peak}$) was determined and HR at the following intensities was established: LOW (HR below 2 mmol·L^{-1}), MODERATE (MOD, HR between 2 and 4 mmol·L^{-1}), and HIGH (HR above 4 mmol·L^{-1}). During field testing, subjects participated in a cyclocross race. HR was monitored throughout the race and [La^-] was measured immediately post. Time in each exercise zone (LOW, MOD, HIGH) was then calculated using data from laboratory testing.
Results: Subjects had an average HR of 170.8±10.1 beats per minute (bpm) and a HR_{max} of 177.8±8.4 bpm during the race. The percentage of time in LOW, MOD, and HIGH was 0.4±0.4%, 6.1±6.7%, and 93.6±6.7%, respectively. No significant mean difference was seen in time (p=0.17) or HR (p=0.29) per lap. Post-race blood lactate was 8.3±1.1 mmol·L^{-1}.
Conclusion: The study shows that cyclocross is a high intensity sport characterized by sustained elevated HR responses and high post [La^-] values.

KEY WORDS: Cycling; Heart rate; OBLA; Performance; Blood lactate; Exercise intensity.

ABBREVIATIONS: HR: Heart Rate; UCI: Union Cycliste Internationale; GXT: Graded Cycling Exercise Test; ANOVAs: Analysis of variance; OBLA: Onset of Blood Lactate Accumulation.

INTRODUCTION

Cyclocross is a subdiscipline of cycling that can be described as a blend of mountain biking and road racing. The sport was introduced in Europe in the 1900s and the first Cyclocross World Championship was held in 1950. Since then, cyclocross has evolved into a popular sport in many European countries, including Belgium, France, and the Netherlands. According to the Union Cycliste Internationale (UCI), the discipline has increased in popularity in recent years, particularly in the United States, Asia, and in women's participation overall.[1] Such recent and relatively high participant growth in cyclocross justifies a better understanding of how the sport's unique physiological demands affect athletes.

Cyclocross races are held on mostly off-road courses 2.5 to 3 km long for 40 to 60 min, depending on racing category. The courses can include a mix of pavement, gravel, grass, and sand and typically include hills, flat sections, and off-camber portions. Courses also include barriers or other obstacles which require riders to dismount and carry their bikes for stretches of the race.[2] The sport is characterized by rapid changes in intensity ranging from highly explosive movements as riders accelerate out of turns to slower sections where riders navigate through more technical elements of the course. According to the UCI, the course terrain and

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obstacle placements must be arranged in a manner that creates a varied race pace, which allows riders to recover from difficult sections.[2] In addition to exceptional bike handling skills, success in the sport seems to rely on an enhanced ability to utilize the anaerobic energy systems for short accelerations of power as well as a strong aerobic system to facilitate recovery between those high intensity bouts. Currently, however, there is little scholarly research to substantiate that claim.

Previous research has described the physiological profile of other cycling subdisciplines such as road racing[3-5] and mountain biking.[6-8] Fernandez-Garcia at al[3] used heart rate (HR) to describe the intensity of the Tour de France and Vuelta a Espana. Similarly, Lim et al[4] used HR and power data to identify time spent above or below lactate threshold during road racing. HR, power, and blood lactate [La^-] have also been used to describe the exercise intensity of mountain biking,[7,8] time trialing,[9] stage racing,[10] and downhill mountain biking.[11] To our knowledge, no studies have described the sport of cyclocross specifically.

Measuring the physiological changes that occur during cyclocross will help to identify the energy systems that predominate during the activity. Determining the exercise intensity of the sport will help to improve training programs designed for cyclocross success, which could have implications for both performance as well as sport participation. The purpose of the current study was to describe the exercise intensity of a field based cyclocross race using HR and [La^-] data.

METHODS

The study was designed to describe the exercise intensity profile of cyclocross racing. Each subject completed a laboratory and a field testing session. During the laboratory testing session, peak oxygen consumption ($\dot{V}O_{2peak}$) was determined and HR and [La^-] were measured during a graded cycling exercise test (GXT). Heart rate and [La^-] values from the laboratory test were then used to identify HR at the following exercise intensities: LOW (HR below 2 mmol·L^{-1}), MODERATE (MOD, HR between 2 and 4 mmol·L^{-1}), and HIGH (HR above 4 mmol·L^{-1}) as described previously.[11] During field testing, subjects participated in an actual cyclocross race. Heart rate was monitored throughout the race and time in LOW, MOD, and HIGH was determined during the race based on laboratory data.

Subjects

Five male and three female subjects completed both the laboratory and field testing. The subjects were experienced, but non-elite cyclocross racers classified as category 2 or 3 according to USA Cycling.[12] All subjects were volunteers and completed informed consent and medical history forms prior to participation. Subjects were excluded if they reported a current injury or a past or present illness on the medical history form. The methods and procedures were approved by the lead author's Institutional Review Board.

Procedures

Laboratory tests: Approximately, 30 days prior to field testing, subjects underwent preliminary screening to determine anthropometric measurements and body composition. Body composition was estimated *via* the skinfold technique.[13] Subjects then performed a maximal GXT on a cycle ergometer (Monark 894 Ea, Vansbro, Sweden). Personal clip-in cycling pedals were affixed to the ergometer. Resistance began at 60 W and increased by 35 W every three minutes until exhaustion. Subjects were instructed to maintain their cadence at 90 RPM. Metabolic variables were analyzed using a calibrated Parvo Medics metabolic cart (True One 2400, Sandy, UT). Capillary blood was taken from the fingertip at the end of each stage to determine [La^-] (Lactate Plus, Nova Biomedical, Waltham, MA, USA). Heart rate was continuously assessed using a Polar RCX 3 HR monitor (Polar Electro Oy, Kempele, Finland). Rate of perceived exertion (RPE) was also assessed each incremental stage using the modified Borg 1-10 scale.[14] The highest consecutive maximal oxygen consumption ($\dot{V}O_2$) values in 1 min were averaged to determine $\dot{V}O_{2peak}$.

Following the GXT testing, [La^-]-heart rate curves were determined and linear interpolation was used to identify the HR and [La^-] at various intensities.[10,11] The following exercise intensity zones were established: LOW (HR below 2 mmol·L^{-1}), MOD (HR between 2 and 4 mmol·L^{-1}), and HIGH (HR above 4 mmol·L^{-1}).[11] Linear interpolation was also used to determine the percentage of $\dot{V}O_2$ at a [La^-] of 4 mmol·L^{-1} (%$\dot{V}O_{2\ OBLA}$).

Field Test: Field testing consisted of participation in a cyclocross race. The race took place on a 2.7 km lapped course on varied terrain including grass, pavement, and barriers. The course was dry and environmental temperature was 3 °C at the start of each race. After pre-race [La^-] was assessed, athletes were allowed to complete a self-directed warm-up. During the race, HR was recorded every 5 s using a coded Polar RCX3 HR monitor (Polar Electro Oy, Kempele, Finland). Blood lactate concentration was measured directly after completion of the race. Heart rate data was transferred to the manufacture's software (Polar Personal Trainer) using a wireless transmitter (Polar DataLink, Polar Electro Oy, Kempele, Finland). Total race time, individual lap time, mean heart rate (HR_{mean}), and maximum heart rate (HR_{max}) were recorded. Time in each exercise zone (LOW, MOD, HIGH) was then calculated using data from the laboratory baseline testing.

Statistical Analyses

Given the exploratory purpose of this study, descriptive statistics were calculated for laboratory and field test variables. One-way repeated measures Analysis of Variance (ANOVAs) were conducted to analyze mean differences in HR and time per lap for each of the 6 laps. An *a priori* alpha level of 0.05 was set. Data analysis was conducted using SPSS version 21 (IBM, New York, NY, USA).

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RESULTS

The mean $\dot{V}O_{2peak}$ for the subjects during laboratory testing was 60.16±9.98 $mL \cdot kg^{-1} \cdot min^{-1}$ and the mean $\%\dot{V}O_{2OBLA}$ was 74.38±9.23%. Descriptive statistics for age, height, weight, body fat, $\dot{V}O_{2peak}$, and $\%\dot{V}O_{2OBLA}$ are presented in Table 1. During the course of the race, on average subjects spent 00:08.8±00:10.3 (mm:ss) in LOW, equivalent to 0.4±0.4% of the race. Subjects spent an average time of 02:27±02:37 3 (mm:ss) in MOD, and an average time of 38:09±03:47 3 (mm:ss) in HIGH, which equates to 6.1±6.7% and 93.6±6.7% of the race, respectively. Heart rate increased immediately at the start of the race and remained elevated for the duration of the effort (Figure 1). Subjects had an average HR of 170.8±10.1 beats per minute (bpm) and a HR_{max} of 182.0±8.4 bpm while participating in the race. In comparison, while participating in the laboratory $\dot{V}O_{2peak}$ test, subjects recorded a HR_{max} of 178.6±7.8 bpm. Subjects had an average $[La^-]$ of 12.0±1.8 $mmol/L^{-1}$ following the maximum graded exercise test in the laboratory. Post-race blood lactate was 8.3±1.1 $mmol/L^{-1}$. A full summary of the descriptive statistics for physiological variables measured in the laboratory and during the cyclocross race are available in Table 2.

Two one-way repeated measured ANOVAs were conducted to examine whether a significant mean increase in time or HR was found per lap over the six laps of the cyclocross race. In the examination of both lap time and HR, the assumption of sphericity was violated (both $ps<0.001$), therefore the Greenhouse-Geisser epsilon adjustment was applied.[15] No significant mean difference was found in time per lap over the six laps, $F(1, 10)=2.16$, $p=0.17$, $\eta_p^2=0.21$. No significant mean difference was found in HR per lap, $F(1, 8)=1.29$, $p=0.29$, $\eta_p^2=0.16$ (Figure 2).

Table 1: Descriptive Statistics for Subject Demographics (*N*=8).

Variable	M	SD
Age (yr)	36.00	4.82
Height (cm)	171.50	9.08
Weight (kg)	68.33	9.20
Body Fat (%)	14.71	2.68
$\dot{V}O_{2peak}$ (L/min)[a]	4.15	0.80
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)[b]	60.16	9.98
$\dot{V}O_{2OBLA}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)[c]	44.56	8.86
$\dot{V}O_{2OBLA}$ (%)[d]	74.38	9.23

[a]absolute peak oxygen consumption, [b]relative peak oxygen consumption, [c]oxygen consumption at a $[La^-]$ of 4 $mmol \cdot L^{-1}$ (onset of blood lactate accumulation), [d]percentage of $\dot{V}O_2$ at a $[La^-]$ of 4 $mmol \cdot L^{-1}$.

Table 2: Descriptive Statistics for Physiological Markers for Laboratory Tests and Race Characteristics.

Variable	M	SD
Laboratory Tests		
$[La^-]_{max}$ ($mmol \cdot L^{-1}$)[a]	12.0	1.8
HR_{max} (bpm)[b]	178.6	7.8
HR_2 (bpm)[c]	115.3	20.1
HR_{OBLA} (bpm)[d]	155.6	13.6
Race Characteristics		
HR_{max} (bpm)[b]	182.0	8.4
HR_{mean} (bpm)[e]	170.8	10.1
% HR_{max}[f]	94.0	2.4
Finish Time (mm:ss)	40:30	2:19
Pre $[La^-]$ ($mmol \cdot L^{-1}$)	1.9	0.7
End $[La^-]$ ($mmol \cdot L^{-1}$)	8.3	1.1
Time in LOW (mm:ss)	00:08.8	00:10.3
Time in MOD (mm:ss)	02:27	02:37
Time in HIGH (mm:ss)	38:09	03:47
% Time in LOW	0.4	0.4
% Time in MOD	6.1	6.7
% Time in HIGH	93.6	6.7

[a]maximum blood lactate, [b]maximum heart rate, [c]heart rate at 2 $mmol \cdot L^{-1}$, [d]heart rate at 4 $mmol \cdot L^{-1}$, [e]mean heart rate, [f]percentage of maximum heart rate.

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Figure 1: Individual Heart Rate Data During Cyclocross Race. For Clarity Purposes, Data from Only Five Participants is Displayed.

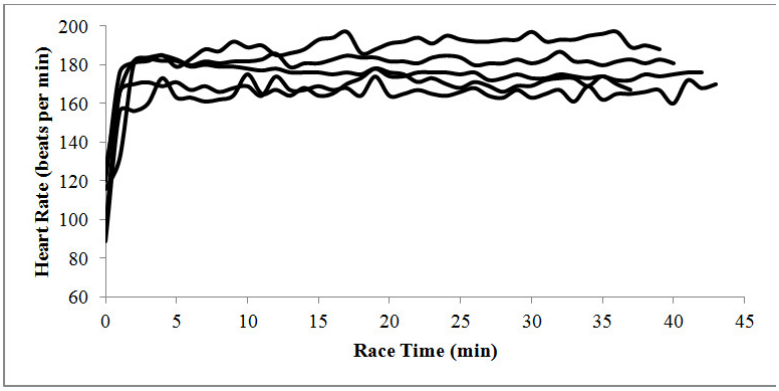
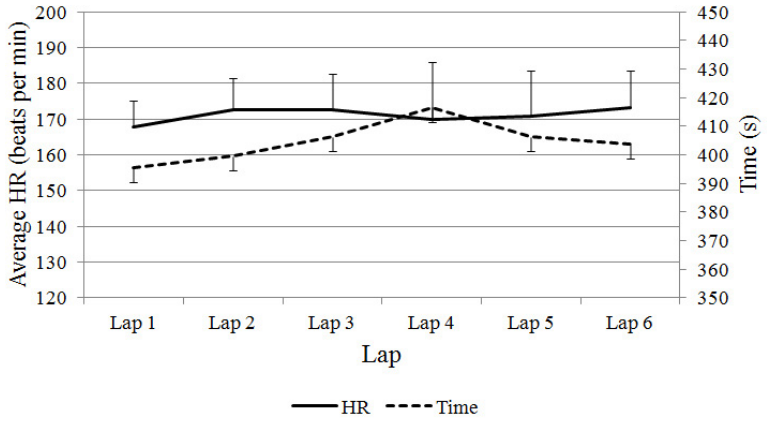


Figure 2: Average Heart Rate (Beats per Min) and Lap Times (s)±SD for Cyclocross Racers Across Six Laps. Note. Average HR (-SD), Time (+SD), N=8.



DISCUSSION

Although, much research has been devoted to describing the exercise intensities of various cycling disciplines, to our knowledge this is the first study to examine the physiological demand of cyclocross racing specifically. The subjects in this study were experienced category 2 or 3 cyclocross racers. The $\dot{V}O_{2peak}$ of the male subjects (63.4±10.8 mL.kg^{-1}.min^{-1}) indicated a high level of fitness, but was lower than values reported for elite male road cyclists and mountain bikers. In their review, Lucia et al[5] reported values between 70 and 80 mL·kg^{-1}·min^{-1} for professional road cyclists and Impellizzeri and Marcora[6] reported values between 66.5 and 78 mL.kg^{-1}.min^{-1} for elite mountain bikers. The values of the males in the current study were similar to those of elite downhill mountain bike racers and were higher than values reported from trained (11±5 h/wk) recreational cyclists.[11,16] The $\%\dot{V}O_{2OBLA}$ (71.8±9.7%) also indicated a high-level of fitness, but was lower than anaerobic threshold values reported in elite cyclists.[5,6] The $\dot{V}O_{2peak}$ values for the females (54.8±4.8 mL·kg^{-1}·min^{-1}) were lower than values reported by Abbiss et al[17] for elite road cyclists, but similar to those reported by Lim et al.[4] The % in females in the current study (78.7±6.5%) indicated a high-level of fitness and was similar to or higher than anaerobic threshold values found in female cyclists.[4,18] These maximal and submaximal fitness variables reflect an enhanced aerobic capacity and are consistent with a group of highly trained, yet non-elite cyclists. Race performance was completed on a 2.7 km lapped course which included elements such as barriers, run-ups, and varied terrain as required by the UCI.[2] Average lap time was 405.67±67 s which corresponded to a speed of 23.9 kph. The purpose of the study was to describe the exercise intensity of cyclocross using heart rate and blood lactate data.

While cycling in general is considered aerobic exercise, the physiological demands of racing various cycling subdisciplines like road, mountain, and cyclocross require a significant contribution from the anaerobic energy pathways as well. Lim et al[4] examined the exercise intensity profile of road cycling by comparing male and female physiological responses to a road race over the same course and distance. In the road race, both the male and female competitors spent a portion of the race below, at, or above lactate threshold (males: 57%, 10%, and 33%;

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females: 62%, 10%, and 28%). In the current study, the percentage of time spent in LOW, MOD, and HIGH zones was quite different (0.4%, 6.1%, and 93.6%, respectively) indicating that cyclocross racing is performed at far greater intensities than road racing. The high intensity effort of cyclocross racing was also confirmed by high blood lactate levels following the race (8.3±1.1 $mmol.L^{-1}$). Road races are of a longer duration than cyclocross races leading to a greater reliance on the aerobic energy system. Lim et al[4] reported a mean time of 03:24:41±00:50:04 for the women's race and 02:39:59±00:46:02 for the men's race. In contrast, the mean finish time for the cyclocross race in the current study was much shorter (00:40:30±00:02:19). The shorter duration of cyclocross racing compared to road cycling events allows for a much higher exercise intensity level that would not be possible to maintain over a longer duration of time. In the same study, Lim et al[4] evaluated the exercise intensity of a criterium race performed over a shorter duration which provides a better comparison to the sport of cyclocross. The mean finish time for the men was 01:02:20 and 01:09:34 for the women. Not surprisingly, the exercise intensity of the shorter criterium race was higher than the road race (males: 63% above LT, females: 71% above LT), but the effort was still far lower than what we saw during cyclocross racing (Time in HIGH=93.6%).

One of the reasons the disciplines vary greatly in exercise intensity is because there is less opportunity to lower intensity by decreasing air resistance (or drafting) in cyclocross than in road and criterium racing. Road and criterium racers can spend much of a race in a sheltered position which can lower energy use by 40% and will lower submaximal, heart rate, and lactate values.[19,20] Drafting is not as common in cyclocross because the technique is not as beneficial at lower speeds and because it is difficult to perform on varied terrain.[21] The relative speed in cyclocross is lower than speeds found on the road due to the increased rolling resistance of the terrain and the need to navigate through obstacles and/or turns in the course. Because of the difference in drafting, cyclocross is a related but different sport than road or criterium racing, defined much less by teamwork and therefore effort sharing. Without the benefit of drafting, exercise intensity remains high in cyclocross throughout the race.

Based on the results of the current study, it seems that the exercise intensity profile of cyclocross is also higher than that of mountain biking. Impellizzeri et al[7] analyzed the effort of mountain bike racers during four cross country races. Heart rate data was used to identify the percentage of time each rider spent in the "easy" (HR below lactate threshold), "moderate" (HR between lactate threshold and OBLA), or "hard" (HR above OBLA) zones during the race. The athletes spent 18±10% in the "easy" zone, 51±9% in the "moderate" zone, and 31±16% in the "hard" zone. Although, the exercise intensity profile of mountain biking is higher than that of road racing, it is still much lower than what we found for cyclocross. According to the UCI, cross country mountain biking races typically range from 90 to 105 min, making them a longer duration than a typical cyclocross race (40-60 min).[22] Similar to road racing, the longer duration event will result in lower intensities and a higher contribution of the aerobic energy system.

The start of a cross country mountain bike race is similar to the start of a cyclocross race in that it is characterized by a supramaximal effort. Athletes typically sprint to get first position before the field encounters either a narrowing of the trail, a significant turn, or an obstacle. If the athlete gets the first position, he or she can then navigate through the varied terrain unimpeded by slower or less technically advanced riders.[6] The explosive nature of the start corresponds with near maximal heart rate values seen almost immediately.[7,8] In our study, we also saw abrupt increases in heart rate within seconds of the start (Figure 1). But while the explosive starts are similar, cross country mountain biking includes significant amounts of descending and thus opportunity for recovery leading to more time in lower intensity zones *versus* cyclocross. In addition, while peak heart rates are seen in the first lap of a mountain bike race because of the intensity of the start, heart rate and lap times tend to decrease as the race continues.[7] This differs markedly from what we found in cyclocross racing where heart rate values peaked immediately and remained high throughout each lap. HR_{max} during the race was higher than HR_{max} recorded during the laboratory testing (182.0±8.4 bpm *versus* 178.6±7.8 bpm). The higher HR_{max} recorded during the race provides some evidence that subjects only achieved $\dot{V}O_{2peak}$ values during laboratory testing. We observed no differences in heart rate or time between laps throughout the race indicating a consistent and high effort for the entire duration (Figure 2).

The combination of the intense start and the stochastic nature of cyclocross could be the reason why heart rate values remained high throughout the race. There are elements of the competition; however, that are less intense. For example, riders must slow to corner around obstacles or to navigate their way through technical elements of the course. The time it takes to move through these sections is short though and frequently followed by maximal sprints leading to large power oscillations during the race. Despite the likely power differences, $\%HR_{max}$ during the race remained high and time in LOW and MOD was minimal. There are a variety of possible mechanisms that may explain the heart rate response to high intensity intermittent exercise. Heart rate increases or decreases due to neural and hormonal input and while changes occur quickly, there is a delay in the response of the cardiovascular system during interval exercise.[23-26] Heart rate recovery takes longer following intense (80% $\dot{V}O_2$ reserve) *versus* moderate exercise (50% $\dot{V}O_2$ reserve).[27] Parasympathetic reactivation has also been found to take significantly longer following exercise using the anaerobic energy pathways.[28] The results of the current study imply that cyclocross requires a large contribution from the anaerobic energy systems. It is likely though that the sport is characterized by abrupt fluctuations in effort such that power values vary widely, but heart rate remains elevated due to the limited recovery time during repeated high intensity bouts. In addition, heart rate is affected by race anxiety or excitement which could cause dis-

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proportionally high heart rates not related to workload.[29,30] While heart rate may be an indicator of whole body effort, it may not fully describe exercise intensity. Future research should examine heart rate-power curves during cyclocross racing so that the intensity of the sport can be more completely described.

CONCLUSION

Cyclocross racing is performed at a higher intensity than road, criterium, or mountain bike racing. The time spent in the HIGH zone in the current study (93.6%) suggests that the sport requires a significant contribution from the anaerobic energy systems. Coaches who design training programs for these athletes should consider this exercise intensity profile in their prescriptions.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

PARTICIPANTS' CONSENT

All subjects were volunteers and completed informed consent and medical history forms prior to participation. The methods and procedures were approved by the lead author's Institutional Review Board.

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