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THE EFFECT OF A CONTROLLED FREQUENCY BREATH HOLDING TRAINING
PROGRAM ON RUNNING ECONOMY AMONG ELITE COLLEGE SWIMMERS

By

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B.S., University of Kentucky, 2011

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A Thesis Approved on

November 21, 2014

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DEDICATION

This thesis is dedicated to my parents

Mr. Jeffrey Sims

and

Mrs. Heidi Sims

who have always been my greatest champions.

ABSTRACT

THE EFFECT OF A CONTROLLED FREQUENCY BREATH HOLDING TRAINING
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Patrick Sims

December 4, 2014

Running economy (RE) is the amount of oxygen consumed while running at a
submaximal intensity. Along with aerobic capacity (VO_{2max}), RE is an important
predictor of running performance. Little research has investigated changes in RE with
restricted breathing training [i.e. controlled breath-holding (CFB)] during exercise. RE
may improve ~6% amongst a novice swimming cohort through CFB training, but this has
not been established in elite swimmers. The purpose was to further establish that CFB
training (16 sessions of 12 x 50-m with ~15 seconds rest between each 50-m, using only
~2 breaths per 50-m) can improve RE in 25 elite college swimmers. CFB training did not
alter RE. The day-to-day variability in RE (mL/kg/km), energy cost (kcal/kg/km), and
VO_{2max} (L/min) was between 2.4 – 3.4%. There was no association between RE (range =
182 to 224 mL/kg/min) and 200 yard freestyle swimming performance (range = 104 to
129 seconds).

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Statement of the Problem

Swimming is a popular sport in collegiate athletics. According to the 2012 United States Census, there were approximately 21,000 National Collegiate Athletic Association (NCAA) swimmers in 2009-2010. In NCAA competition, competitive swimmers compete with one of four swimming strokes, each with its own unique rhythmicity, including butterfly, breast stroke, backstroke, and front crawl, sometimes known as, "freestyle" (Gupta & Goswami, 2001). This thesis focuses on 200 yard freestyle swimming performance in NCAA swimmers at the University of Louisville.

Freestyle swimming uniquely limits access to ventilation as dictated either by stroke choice/frequency, athlete's choice, or both, whereas terrestrial sports provide unfettered access to ventilation patterns of one's choosing. In this way, swimming training as a primary discipline may cause substantial change to one's respiratory performance (McKay, Braund, Chalmers, & Williams, 1983). Oxygen consumption at any intensity (VO_2), (and at maximal int®ensity, VO_{2max}) represents a culmination of musculoskeletal, cardiovascular, and respiratory function. In the elite athlete, the respiratory system may be a limiting factor to endurance performance (Bye, Farkas, & Roussos, 1983; Lavin, Guenette, Smoliga, & Zavorsky, 2013). Swimming is an

interesting event to study the respiratory system since swimmers usually have very large lungs (Andrew, Becklake, Guleria, & Bates, 1972).

Although an athlete's aerobic capacity (VO_{2max}) has traditionally been assessed via a graded exercise test to volitional exhaustion, running economy (RE) can also be measured this way. Running economy is the submaximal VO_2 at any given running speed and is usually expressed in terms of milliliters of oxygen consumed per kilogram of body weight per kilometer of distance traveled (mL/kg/km).

Technically, the term, "economy" is most specific to the amount of oxygen consumed at submaximal intensity, while the term, "efficiency" refers to the amount of work done per unit of speed. Since running velocity is not a direct measure of work, efficiency is technically a different index. With that said, the terms economy and efficiency are frequently used interchangeably in the existing literature on running economy (Luhtanen, Rahkila, Rusko, & Viiasalo, 1990; Yoshida, Udo, Iwai, & Yamaguchi, 1993) and may be used interchangeably within this document, assuming both are queries into one's oxygen consumption versus their running velocity.

The measurement of RE has been shown to be a good predictor of endurance performance when runners of the same aerobic capacity are matched (Conley & Krahenbuhl, 1980; Conley, Krahenbuhl, Burkett, & Millar, 1981; J. T. Daniels, 1985; Morgan, Martin, & Krahenbuhl, 1989). Running economy is an expression of one's overall physiological efficiency, while aerobic capacity is the measurement of one's physiological "power". In other words, the lower the amount of oxygen required to run a given distance (normalized to body mass), the more physiologically efficient one is.

Running economy could be equated to the fuel economy of a car, wherein less fuel per mile used represents a more economical vehicle. VO_{2max} on the other hand would be represented in a vehicle's horsepower; a measure of capacity to create maximal amounts of work irrespective of fuel cost. Thus, a Toyota Prius may be a very efficient car with little horsepower, while a Ford Mustang is more powerful but not efficient.

This balance of economy and capacity has led to much investigation of the intersections of RE and VO_{2max}; the relationship is debated and appears to differ greatly based on the population and study in question. Some studies have found that there is a negative relationship between RE and VO_{2max}, suggesting that as the amount of oxygen that is required to run a given distance decreases, VO_{2max} is increased (Morgan et al., 1995; Morgan & Daniels, 1994; Padilla, Bourdin, Barthelemy, & Lacour, 1992; Pate, Macera, Bailey, Bartoli, & Powell, 1992; Tartaruga et al., 2013).Other research has found that RE and VO_{2max} in fact are not related (Anderson, 1996; Mooses et al., 2014; Reeves, Corbett, & Barwood, 2014; Santos-Concejero et al., 2014), and yet others have found that as RE gets worse (VO_2 increases) VO_{2max} is low between the two (Mooses et al., 2014) To complicate matters, research has even found that, while related, RE and VO_{2max} can fail to predict running performance (Grant, Craig, Wilson, & Aitchison, 1997). On the whole, the relationship between RE and VO_{2max} is complicated in research and not fully agreed upon.

A recent investigation found that RE could be improved by a particular swimming training, namely by restricting breathing during swimming training (Lavin et al., 2013). This is accomplished by inspiring air to total lung capacity (TLC) and then holding this air for several strokes before taking another breath. This technique, called controlled

3

frequency breath holding (CFB) may improve swimming performance by training the respiratory muscles to become fatigue resistant. Lavin *et al.* demonstrated that limiting breathing frequency in swimming training resulted in faster swimming times and improved RE (Lavin et al., 2013). They postulated that there was an improved muscular oxygen utilization since RE was improved (VO_2 was lower) among recreational swimmers.

Lavin *et al.* did not investigate what the mechanism of improvement was exactly, although they suggested that the improvement in RE was a result of a change in peripheral muscle. The rate of oxygen diffusion into the mitochondria has been established as one limiting factor of VO_{2max} (di Prampero, 2003), so this is a potential site for improvement, although the mechanisms by which hypercapnia may affect oxygen diffusion at the cell is not well understood. Some research has looked at effects of hypercapnia on relationships between cerebral oxygen diffusion and the enzymes cytochrome C oxidase and nitric oxide synthase (Gjedde, 2005), but this cannot be assumed to apply likewise to skeletal muscle.

No matter the mechanism of change in Lavin's cohort, it has yet to be investigated whether the same results can be replicated among elite swimmers, who presumably already possess substantial respiratory muscle strength. Among a well-trained cohort of triathletes that increased swimming and cycling volume by ~50%, their RE or VO_{2max} were not altered compared to before the study began (Palazzetti, Margaritis, & Guezennec, 2005). Thus, sheer volume of exercise will not suffice. Therefore, it bears investigating just what cardiopulmonary training interventions may improve oxygen consumption in swimmers.

Running economy, being an expression of one's oxygen consumption for a given running speed, is an important factor apart from one's VO_{2max}, which has been thoroughly investigated as a major indicator of aerobic potential (Barnes & Kilding, 2014). The body of research on factors affecting RE is substantially smaller than that of VO_{2max}, and stands to be developed greatly in emerging literature. Running economy should be assumed to always represent the physiological efficiency of one's movement while at submaximal intensity. The state of the literature currently shows several factors that may modestly affect RE, although only one up to this point has investigated RE among swimmers, and then with a recreationally fit subject pool. Mechanisms established as affecting RE are many, including, but not limited to: training volume and longevity (Midgley, McNaughton, & Jones, 2007), biomechanical differences among athletes (Santos-Concejero et al., 2013), shoe design (Sobhani et al., 2014), minute ventilation (V_E), altitude, hypoxia, core temperature, (Saunders, Pyne, Telford, & Hawley, 2004a) and more. Each of these influences will be examined in-depth below as potential informants on this intervention.

1.2 Purpose of the Study

This study aimed to assess whether a four week intervention of controlled frequency breath holding (CFB) training can improve either RE or VO_{2max} among elite, collage-aged swimmers. The four week protocol was selected to accurately recreate the intervention used by Lavin *et al.* (2013).

Utilizing the experimental procedures of Lavin *et al.* (2013), this study focuses on an elite swimming cohort, which is an interesting group to study due to their enhanced

conditioning. The potential that a lifetime of swimming has positively influenced the respiratory development of these subjects is not ignored; childhood and adolescent vigorous swimming training has previously demonstrated augmentation of total lung capacity (Andrew et al., 1972; McKay et al., 1983; Sarro, Silvatti, & Barros, 2008; Zinman & Gaultier, 1987) . All subjects within this cohort were competitive swimmers since adolescence.

1.3 Significance of the Study

Demonstrating a relationship between RE and swimming performance may show that CFB training can improve changes at the muscular level, allowing locomotor muscles to perform the same amount of work with less oxygen. If CFB training can indeed improve RE among an elite cohort of swimmers, the common crossover of swimming to multisport post-collegiate competition may bring with it important training methodology for improving terrestrial performance. Likewise, demonstration of improvement in RE or VO_{2max} by CFB training would invite further scholarly research to see if CFB training can be used exclusively terrestrially to improve RE among non-swimming athletes.

1.4 Literature Review

1.4.1 Running economy versus maximal oxygen consumption

As mentioned above, the relationship between VO_{2max} and RE is highly debated. Some research suggests VO_{2max} may be positively related to RE (Mooses et al., 2014). Thus, the more oxygen that is required to cover a given distance, the higher the RE. The homogenous group in question, elite Kenyan distance runners, who had worse RE than a

European comparison group, still demonstrated superior VO_{2max} values and were extremely successful athletes despite worse RE, suggesting that, a high VO_{2max} can more than compensate for poorer RE in terms of total athletic potential. What seems to be highly variable is the RE even among their elite cohort. Mooses *et al.* stated that the differences in RE among the subjects was mostly mechanically related. These findings are supported by Santos-Concejero *et al.* who found that a similar pool of North African runners demonstrated inferior RE to a comparable European subject pool as well as longer ground contact time in stride, but are still more athletically successful (Santos-Concejero et al., 2013). In disagreement with this, Weston *et al.* found that African runners were 8% more economical than Caucasian 10km runners, but had a 13% lower VO_{2peak} (Weston, Mbambo, & Myburgh, 2000). Some researchers have gone so far as to speculate that neither of these factors predict running performance (Grant et al., 1997).

However, a large body of research suggests that RE and VO_{2max} are indeed negatively related (Morgan et al., 1995; Morgan & Daniels, 1994; Pate et al., 1992). That is, the less oxygen that is needed to cover a given distance, the higher the subject's VO_{2max}. Among those who found a negative relationship between RE and VO_{2max}, it was asserted that RE is identical across sexes. (Padilla et al., 1992). Pate *et al.* demonstrated a positive association between RE and VO_{2max} among a heterogeneous group of recreational runners, while Morgan *et al.* showed this negative relationship to hold true across a breadth of running skill level from novice to elite (Morgan et al., 1995). They claimed that previous research failing to associate RE and VO_{2max} among elite levels is attributable to the amount of years at elite training status. They asserted that increases in training years appear to improve association of RE and VO_{2max}.

7

A disparity exists in the effects of VO_{2max} and performance between running and swimming; running performance is significantly correlated a runner's relative, but not their absolute, VO_{2max}, whereas a swimmer's performance is correlated with their absolute, but not relative, VO_{2max} (Butts, Henry, & McLean, 1991). This suggests that there is an incongruent interaction of maximal aerobic capacity in running and swimming, such that the latter is simply a matter of, "the size of the engine," while the former is contingent on body size interaction with VO_{2max}.

Among swimmers, who presumably spend little to no time running, there can be assumed to be little influence of time-at-training specific to running biomechanics, which helps narrow the confounders of RE such that the results of this study might truthfully demonstrate any effects of CFB training.

1.4.2 Running Biomechanics and Running Economy

Several pieces of literature have substantiated a major influence of biomechanics on RE. Since this piece of research seeks to examine whether manipulation of the myriad factors surrounding pulmonary function can augment RE, it could prove a novel intervention for improving RE beyond the current state of the literature which has demonstrated mainly the influences of biomechanics.

The metabolic cost of running is significantly increased by wearing shoes versus barefoot running (Reeves et al., 2014). Additionally, the particular shoe worn changes RE (Sobhani et al., 2014). Logically, the addition of mass at the bottom of the foot increases the amount of torque required to complete each running stride and therefore would augment RE. Mooses *et al.* demonstrated a positive association between RE and Achilles

tendon moment arm, as well as upper leg length (Mooses et al., 2014), which stands to support that the increase in leg mass is equitable to a worsening in RE.

To that effect, RE appears to be best in those with the smallest leg masses (Kong & de Heer, 2008) among elite runners. More widely, the effect of body mass has been shown to affect RE but not percent body fat (Pate et al., 1992). With that said, the groups will be randomized to help eliminate influences in body mass.

RE is not significantly correlated with the kinetic factors of contact time or step frequency, suggesting that personal biomechanical characteristics of running stride does not explain differences in RE; instead, it has been shown that the horizontal force in the braking phase (eccentric loading phase of ground contact in the foot strike) of the running stride is the main factor explaining oxygen consumption. The amount of vertical and mediolateral forces created during ground contact account for a great percentage of the variance in RE; higher mediolateral forces are associated with athlete with less efficient (higher) RE values (Kyrolainen, Belli, & Komi, 2001). In support of these findings, instructional interventions to modify running stride which succeed at decreasing stride length and increasing stride rate also fail to change RE, heart rate (HR), or ratings of perceived exertion (RPE) (Craighead, Lehecka, & King, 2014). This is important for this investigation, as it challenges any assertion that "learning" of running would improve RE.

RE has been also shown to me related to the mechanical factors of muscle. The less flexible a runner as demonstrated in seated sit-and-reach test, the better their RE, presumably due to increased elastic recoil of the muscle stretch-shorten cycle (Trehearn & Buresh, 2009). These findings were supported by the work of Hunter *et al.* who found

that decreased lower limb flexibility and increased lower limb tendon length were associated with better RE (Hunter et al., 2011).This information is important for building a context that RE is strongly related to anatomical characteristics of the subject, which may complicate training interventions which aim to affect RE.

1.4.3 Heart Rate and Running Economy

The positive, linear association between heart rate (HR) and VO_2 is well documented (Dalleck & Kravitz, 2006; Strath et al., 2000; Swain, Leutholtz, King, Haas, & Branch, 1998). However, training can affect maximal heart rate (HR_{max}) with higher values associated with de-training (being out of shape) and lower values associated with increased fitness (Zavorsky, 2000). As discussed above, the relationship between VO_{2max} and RE is highly contested, which complicates the relationship of RE to HR. Binnie *et al.* did find that improvements in HR at submaximal effort and like factors such as blood lactate concentrations (BLa) occurred simultaneously with worsening (increase in VO_2) in RE. (Binnie et al., 2014). In conflict with this, Pate *et al.* found that improvements in RE coincide with lower HR (Pate et al., 1992).

1.4.4 Respiratory Muscle Fatigue, Hypoxia, Altitude and RE

With a design on reducing respiratory muscle fatigue in swimmers, this study relies heavily on existing literature to dictate to what extent respiratory muscle fatigue, and the training to reduce respiratory muscle fatigue may affect terrestrial exercise economy and capacity. Much research in RE has been conducted implementing environmental hypoxia (low partial pressure of oxygen in inspired air due to high altitude). Exposure to altitude, which can readily be considered an environmental

stimulus for hypoxia, has been shown to worsen RE (+7%) for those previously living at sea level, even after 46 weeks of acclimatization to moderate altitude (2,210-m). (Brothers et al., 2010). Brothers *et al.*'s findings call into question whether short-term, acute exercise interventions to induce hypercapnia may generate enough stimuli for change, if nearly a year of ambient hypoxia via moderate altitude cannot. This study is unlike the altitude studies in that the participants will have very limited exposure to hypercapnia, versus intermittent environmental exposure to hypoxia via altitude.

Saunders *et al.* found that 20 days of simulated altitude residence (simulated 2000-3100-m. altitude, 9-12 hours per night while sleeping) with low-altitude training (known as, "live high, train low") can elicit a ~3% improvement in RE versus both moderate-altitude residence and training, or low-altitude residence and training (Saunders, Telford, et al., 2004). Subjects did not demonstrate a decrease in minute ventilation. They confirmed their findings by exposing a subsequent group (Saunders, Telford, Pyne, Hahn, & Gore, 2009) of runners to ~50 days of simulated altitude residence with low-altitude training and found a 3% decrease in oxygen consumption (3% improvement in RE). Their increase in time exposure to live-high, train-low hypoxia for runners elicited the same improvement in RE as their shorter intervention length, suggesting that time-at-exposure to hypoxia is not the only factor at play in improving RE. Their findings are complicated by the fact that hemoglobin mass only very slightly, but significantly, improved (+5%, $p = 0.01$), while no improvement in VO_{2max}, further suggesting that RE and VO_{2max} are physiologic variables with a complicated relationship.

1.4.5 Controlled Frequency Breath Holding and RE

While breath-holding during swimming may be thought to elicit hypoxemia, it does not if one hold his/her breath at TLC (Woorons, Gamelin, Lamberto, Pichon, & Richalet, 2014). Instead hypercapnia (partial pressure of arterial carbon dioxide > 45 mmHg) ensues. (Woorons et al., 2014). However, holding one's breath for a period of time after complete exhalation (residual volume, RV) does result in exercise-induced hypoxemia, simulating hypoxia (Woorons et al., 2014).

Until now, only one study used CFB training (at TLC) to elicit hypercapnia in swimmers (Lavin et al., 2013). They showed that CFB training improved RE by 6% and 150 yard swimming performance by 8%. However, these swimmers were recreational swimmers and it may have been quite easy to improve swimming performance and RE in novice swimmers with relatively slow swim times (150 yards short course swim time was initially 157 ± 27 s). This research caveat is known as the "floor effect" in which subjects who are near the bottom in terms of performance have no other direction to go but upward. Thus, any intervention in these subjects may elicit improvements in performance. For this reason, our investigation remains novel and important; if regular hypercapnic training via CFB proves to be a proponent of improved RE in an elite cohort, it may help direct further research in respiratory interventions for improving exercise economy.

It is well-established that the prior training status of a subject will affect RE, and that trained subjects demonstrate superior RE to untrained subjects (J. Daniels, Oldridge, Nagle, & White, 1978; J. T. Daniels, 1985). For the purposes of comparing the results of

this investigation to those of Lavin, it is prudent to consider this current subject pool as, "elite," although not as runners, which logically tends to be the population investigated most often in RE research.

To this point, association of RE and swimming performance has not been established. The Lavin *et al.* paper did not publish statistical association between recreational athlete's RE and swimming performance, although they later mentioned to me that there was none ($r = 0.32$, $p = 0.23$, Personal Communication, 2014) . This investigation will seek to establish determine if there is an association between RE and 200 yard swimming performance in elite NCAA swimmers.

1.4.6 Allometric Scaling of RE

It is common practice to express the RE value in the form of VO_2 per kg of body mass per unit distance traveled (i.e. mL/kg/km). However, this body mass (BM) specific scaling has been questioned as valid for comparison because increases in VO_2 are not proportional to increases in BM (Bergh, Sjodin, Forsberg, & Svedenhag, 1991). It has been substantiated that RE has statistical association with RE at the $BM^{-.066}$ or $BM^{-0.75}$ values rather than just for BM^{-1} (Saunders, Pyne, et al., 2004a).

1.4.7 Operational Definitions for literature review

Term	Abbr.	Term	Abbr.
Controlled Frequency Breathing (intervention group) (2 breaths per 50-m length)	CFB	200 yard Swim Performance Time (seconds)	SPT
Running Economy (ml/kg/km; kcal/km/km)	RE	Aerobic Capacity (L/min; mL/kg/min)	VO_{2max}
Stroke-Matched Breathing (control group) (10 breaths per 50-m length)	SM	Heart Rate (beats/min)	HR
Global, whole body, oxygen Consumption (L/min, mL/kg/min)	VO_2	Rating of Perceived Exertion (6 to 20 scale)	RPE

1.5 Research Questions & Hypotheses

1. Does a four-week training program of CFB training improve RE and VO_{2max} in elite NCAA swimmers?

Specific Aim: To investigate response of oxygen utilization at submaximal and maximal efforts while running after CFB intervention.

Hypothesis 1.1: Running Economy will significantly improve by 15ml/kg/km after CFB training and remain unchanged in SM control group as seen in the results of Lavin *et al.* (2013).

Hypothesis 1.2: VO_{2max} will remain unchanged in either CFB or SM control groups

2. Does a relationship exist between RE and swimming performance?

Specific Aim: Establish association of RE as expressed in VO_2 (mL/kg/km) with swimming performance in a 200 yard freestyle swimming time trial.

Hypothesis 2: There will be a significant relationship between RE and 200-yd freestyle swim performance.

1.6 Assumptions

Certain assumptions have been made throughout our study. We assumed that all participants were healthy and well-conditioned. It was not investigated as to how many of our subjects were also recreational runners. We also assumed that these subjects were able to give a best effort for all their testing sessions. To limit error here, the subjects had to meet three established criteria for attaining VO_{2max} in their testing battery according to ACSM guidelines (ACSM, 2013). Finally, we assumed that these subjects were able to complete all training sessions as necessary.

CHAPTER 2

METHODS

2.1 Subject Selection

A convenience sample of NCAA Division I swimmers from the University of Louisville were recruited to participate in this research. Subjects were not chosen randomly. This research has designated all subjects as, "elite," which is requisite of their position on a Division I swim team ranked within the top 10% for Division I eligible programs. Subjects were an equal, mixed-sex sample. Elite swimmers were desired for this investigation to evaluate whether the results of Lavin *et al.* (2013) were reproducible in an elite cohort of non-terrestrial athletes.

Whether subjects were more traditionally sprint or endurance swimmers was not of particular interest to investigators, as we desired to acquire as diverse a sample of elite college swimmers as possible.

To be eligible for this study, subjects must have competed for the University of Louisville at some point during the 2013-2014 collegiate swim season. No performance-based metrics such as time-per-distance swum were set for inclusion. The age of subjects was limited to those in agreement with NCAA competition eligibility criteria. Twenty-four subjects were needed for this study.

2.2 Settings

All study intervention and testing was conducted on the University of Louisville campus. Intervention procedures were executed within the Ralph Wright Natatorium. Running economy and VO_{2max} testing were conducted in the Exercise Physiology lab of Crawford Gym.

2.3 Procedures

2.3.1 Pre and Post-Testing

All subjects attended a pre-participation information session led by study investigators where subjects were asked to read and sign an informed consent document which detailed their responsibilities and risks of study participation.

Pre-testing of athletes consisted of two testing batteries of RE and VO_{2max}. The first was a full familiarization session of the entire running battery procedure (explained below), and then within one week, participated in baseline data battery for RE and VO_{2max}. Familiarization and baseline data were compared post-hoc to determine day-to-day variability and reproducibility. All tests were conducted on the Woodway ELG treadmill (Woodway USA, Waukesha, WI). Metabolic testing was conducted using the PARVO Medics TrueOne 2400 metabolic cart (PARVO Medics, Sandy, UT).

Two pre-intervention testing sessions were administered, the first for test procedure familiarization and then within one week for baseline. At familiarization, subjects were measured for age in years, anthropometrics including height (m), weight (kg), and body composition via hydrostatic weighing. Body composition was calculated according to the Siri and Brozek equations for hydrostatic weighing, with results being

recorded as the average of the two equations (Brozek, Grande, Anderson, & Keys, 1963; Siri, 1993). Body composition was measured to allow comparison of anthropometrics of our subjects to other investigations both past and future. Participants were allowed to change clothes to prepare for the running portion of familiarization. All running trials followed the same procedure; running speeds were pre-determined by investigators respective to sex.

Three, 5-minute submaximal running stages were performed. Running at all speeds was conducted on 0% incline. Submaximal stage one was conducted at 6 mph and 5.5 mph for male and female subjects, respectively. Submaximal stage two was conducted at 7mph and 6.5mph for male and female subjects, respectively. The third submaximal stage was conducted at 8mph male subjects, 7.5mph for female subjects. Between the first two submaximal stages, and between the second and third submaximal stage, a passive rest period of five to seven minutes was permitted, with all subjects beginning the next stage in no fewer than five, and no more than 6.5 minutes. Participants did not perform any active recovery or physical activity during these inter-stage recovery periods.

At the end of the third submaximal stage, subjects did not participate in a passive recovery period, but rather proceeded on a graded exercise protocol up to maximum volitional fatigue. After the five minutes at the third submaximal stage, the graded exercise progressed every two minutes with a 1.0 mph increase until maximal fatigue was achieved. Indices measured at all running speeds included HR, VO_2, and RPE. Data recorded at maximal intensity included HR_{max}, VO_{2max}, minute ventilation at maximal

exercise [VE_{max} (L/min)], respiratory exchange ratio (RER_{max}), and maximum oxygen pulse (O_2Pulse_{max}).

Economy was calculated as VO_2 in mL/kg/km for the final three minutes of each submaximal speed, and then averaged at all speeds to create one value reported as the overall RE. Units for RE was also reported in kcal/kg/km.

Post-intervention testing was conducted exactly according to the protocol for both familiarization and baseline sessions. Hydrostatic weighing was recorded only at the familiarization session. Values recorded at familiarization were retained in order to assess day-to-day variability in RE without training effect to inform on necessary magnitudes for meaningful change. Subjects also completed a 200m freestyle swim time trial at maximal volitional effort at BASE and POST in order to investigate correlation between RE and swimming performance as well as to investigate performance improvements.

2.3.2 Training Intervention

Subjects, who were divided into two groups, intervention and controls, participated in sixteen (±2) study sessions within a four-week period (±5 days). Each study session was approximately thirty-five minutes in duration. All subject began with a standardized 1000-m warm up of easy, mixed-stroke swimming.

All subjects participated in the same training intervention workout profile, consisting of 12 repetitions of a 50-m swim completed within a one-minute interval for the first week of the study. Weeks two and three decreased the interval by five seconds, to 55 seconds per rep. An additional five second decrease occurred during the final week

of training set the intervals at 50 seconds per rep (see Table 3 for the complete training regimen).

The CFB training (intervention) group was instructed self-limit their breathing to two breaths per repetition, resulting in about 24 breaths per workout (only breaths taken during repetitions were counted for workout totals), while controls were allowed to breathe on a stroke-matched basis, breathing every 2-3 strokes accumulating 10-12 breaths per lap. At the end of each workout, all subjects self-reported their number of breaths taken during the workout, as well as reporting their RPE using the 6-20 Borg scale (Borg, 1982). All study training sessions were supervised by at least one member of the University of Louisville swimming coaching staff.

2.3.3 Research Design

The research design implemented for this study was a pre-post test design with control group. This was a quasi-experimental design in which a convenient sample of elite college swimmers was used. To examine changes in RE and VO_{2max}, a 2 x 3 repeated measures analysis of variance was used. The independent variable was the training program [Experimental Group = CFB training group; Control group = stroke matched (SM) group] and the number of measurements per variable (three measurements per variable: familiarization session, baseline, and post-testing). The Lee notation was represented as: $S_{12} \cdot (G_2) \cdot T_3$ in which subjects were nested within group (2 groups, CFB, SM) and crossed with time (familiarization, baseline, post-testing).

2.3.4 Statistical Analysis

Sample size calculation was estimated from the mean overall changes for RE with and between groups from Lavin *et al.* (2013). Using online statistical software (G*Power Version 3.1.7, Universität Kiel, Germany), the following was calculated for the within-between interaction for repeated measures ANOVA: statistical power was set at 80%, type I error rate at 5% ($\alpha = 0.05$), correlation among repeated measures $= 0.90$, and effect size $f = 0.0135$. A total of 24 subjects was estimated. Twenty six subjects matriculated into the study to allow for an approximate 10% attrition rate.

The data was analyzed with the SPSS statistical software package (SPSS Version 21.0, IBM SPSS Statistics Inc., Chicago, IL). Statistical significance was be declared when $p < 0.05$ unless otherwise noted.

To compare groups at baseline, independent *t*-tests were performed. For the variables that were not normally distributed, a Mann-Whitney U Test was used to compare groups. To compare cardiopulmonary variables from the graded exercise test between familiarization and baseline sessions, paired *t*-tests were used. If the variables were not normally distributed, a Wilcoxon Signed Rank test was used.

The repeated measures analyses of variances were used to assess statistical significance of results post-intervention versus baseline with a Bonferroni correction. Pearson product moment correlations were performed for establishing relationships of swimming performance time to RE.

Indices of responsiveness to CFB training was calculated according to previous methods (Kim, Mayo, Carli, Montgomery, & Zavorsky, 2009; Salbach et al., 2001).

Effect size (ES) was defined as the mean change of the variable between baseline and post-training divided by the SD of the variable at baseline. An effect size of 0.0 to 0.2 was considered trivial, 0.2 to 0.5 was small, 0.5 to 0.8 was moderate, and 0.8 and above was strong. The standardized response mean (SRM) was calculated as the average change divided by the SD of the change. The *t*-statistic was defined as the mean change of the variable between base-line and post training divided by the standard error (which is the SD divided by the square root of the sample size).

For the dependent variables that were not altered between familiarization and baseline sessions, the day-to-day coefficient of variation was calculated as the mean of the two trials divided by the standard deviation of the two trials x 100. Measurement error (otherwise known as the typical error or the within subject standard deviation) was calculated as the square root of the within-subjects error variance (i.e., the within-subject standard deviation) derived from a repeated measures ANOVA. Reproducibility was defined as 2.77 × the measurement error (Bland & Altman, 1996). That is, the difference between two measurements obtained on different days for the same subject is expected to be less than 2.77 times the within-subject standard deviation for 95% of pairs of observations (Bland & Altman, 1996). Since the calculation of reproducibility may be considered too stringent, the smallest meaningful change was reported as half of the reproducibility (Hopkins, 2000).

2.3.5 Data Management and Storage

All data for RE was recorded digitally within the hard drive associated with the PARVO metabolic cart, and redundantly printed after each stage for all subjects. RPE

values and between-stage recovery time values were recorded manually by investigators during the test. All data pertaining to the study was kept within a locked room in a locked filing cabinet with access granted only to the investigators managing the study.

CHAPTER 3

RESULTS

Twenty-five swimmers from the University of Louisville completed the

familiarization and baseline sessions. Table 1 depicts the subject characteristics. No

statistically significant difference existed between groups or between sexes. The 200 yard

freestyle swimming times at the baseline session (short course) for all 25 subjects was

115 (SD 7) seconds (range 104 to 129 seconds). There was a mean day-to-day

coefficient of variation of 1.4% (SD 1.6%) in swim times between the familiarization and

baseline sessions. This equates to a day-to-day typical error of 1.6 seconds for the 200

yard race (day-to-day reproducibility =   4.5 seconds; smallest meaningful change = 2.2

seconds).

Table 2 depicts the cardiopulmonary data obtained from treadmill testing of all

subjects between familiarization and baseline sessions. The only dependent variables that

showed a difference between these two sessions was running economy (mL/kg/km,

p=0.01), energy cost (kcal/kg/km, p = 0.02) and HR_{max} (beats/min, p= 0.03), although all

were small changes and likely not meaningful due to all having trivial effect sizes.

Table 3 depicts training results of each group. Four of the 25 subjects failed to

complete all of their follow-up testing. One left town and was not able to return to

testing, while the other three decided that it was no longer worth their time to participate

in the study. There were no significant changes in any dependent variable, suggesting that neither groups experienced any measurable physiological changes.

Since there were no meaningful differences between most dependent variables between familiarization and baseline sessions (Table 2), we were then interested in the day-to-day variability and other similar indices for implementation in future studies. These indices of reproducibility are presented in Table 4.

There was no significant association between RE and 200-yd swimming times (n = 25, r = –0.25, p = 0.23) at baseline. However, 69% of the variance in aerobic capacity was accounted for by difference in swimming times (Equation 1).

Equation 1: 200-yd swim time (s) = $-6.87 \cdot (VO_{2max}$ in L/min) $+142.8$, SEE 3.8, p < 0.01

CHAPTER 4

DISCUSSION

4.1 Discussion Overview

The purpose of this study was to assess whether CFB training can improve either RE or VO_{2max} among elite, college-aged swimmers. This investigation did not find any improvements in RE or VO_{2max} in either group.

This is the first study that evaluated the effects of CFB training on RE in an elite cohort of swimmers. The previous investigation of this kind was limited to recreational multi-sport athletes (Lavin *et al.* 2013). Our failure to find any significant change in RE from the CFB intervention conflicts with the findings of Lavin *et al.* who found an improvement (that is to say, lower VO_2 at a given sub-maximal running velocity) in RE of ~15ml/kg/km, or ~6%. As Lavin's authors noted, their demonstration of change to performance was presumed to be a not-yet understood improvement in peripheral, vascular physiology. Just what precipitated the results in the Lavin cohort but not this one is likely due to the difficulty of eliciting change in the elite athlete, for whom the threshold for improvement is extremely high, with the potential for improvement very small.

With that said, the failure to achieve significant improvement in RE is consistent with some previous research that indicates that RE is not easily improved, nor perturbed,

26

by factors of training stimulus alone. An overload of training volume of up to 50% among well-trained triathletes cannot significantly affect RE (Palazzetti et al., 2005). Palazzetti *et al.* utilized an intervention lasting three weeks, which is of similar duration to this investigation; it is possible that our intervention was not of great enough duration, despite significant results in a novice cohort as demonstrated elsewhere (Lavin et al., 2013).

Brothers and coworkers demonstrated that nearly a year spent at 6,000-ft of altitude demonstrated a worsening (that is to say, higher VO_2 at a given sub-maximal running velocity) in RE, suggesting that physiological improvements in RE are slow to change due to environmental factors (Brothers et al., 2010).

4.2 Normal values for RE

Later, Morgan and colleagues determined that in runners who competed in the 1984 U.S. Olympic trials had a mean RE of 182 (SD 9) mL/kg/km with a range of 162 to 196 mL/kg/km (Morgan et al., 1995). In contrast, this study used swimmers, and their RE ranged from 182 to 224 mL/kg/km with mean of 203 (SD 11) mL/kg/km. Our elite cohort of swimmers demonstrated inferior RE to an elite running cohort. In fact, the mean RE in this swimming cohort was similar to the RE of physical education majors [202 (SD 12) mL/kg/km] not accustomed to run training (Morgan et al., 1995). Our subjects did demonstrate a much narrower range among their RE values than in the elite runners of Morgan *et al.*, suggesting they were a very physiologically similar group. Additionally, the "poor" RE determined my Mooses and colleagues (Mooses et al., 2014) found that

the average RE of elite Kenyan runners was 229 (SD 13), which supports the assertion that RE is only one variable of many that predict running performance.

Our research found that the reproducibility in RE was 11.8 mL/kg/km. That is, the difference between two measurements obtained on different days for the same subject is expected to be less than 2.77 times the within-subject standard deviation (Bland & Altman, 1996). The within subject standard deviation is otherwise known as the typical error. Thus, with an observed difference in RE between day 1 and day 2 differs by more than ± 11.8 mL/kg/km, there is a 97.5% probability that the change is indeed real (39 to 1 odds), and only a 2.5% probability that it is not a true change. According to Will Hopkins, this degree of certainty about a true change unrealistic (Hopkins, 2000). He suggests that half the limit of agreement seems a more reasonable threshold; when an observed change in RE differs by more than ± 5.9 mL/kg/min in our cohort of swimmers, there is an 84% probability that the change is indeed real (5 to 1 odds), and only a 16% probability that it is not a true change. This is approximately 1.5x the typical error (i.e. 1.5x the measurement error) which is a more realistic threshold according to Hopkins. Thus, the smallest meaningful day-to-day change in RE converted to a percentage would be about 3%, which is similar its day-to-day coefficient of variation of 2.4% (Table 5).

This is in contrast to Saunders *et al*. who state that among elite runners, changes in RE greater than 2.4% should be considered meaningful (Saunders, Pyne, Telford, & Hawley, 2004b; Saunders et al., 2009). Shaw *et al*. demonstrated that the within subject standard deviation (i.e. the typical error) for both RE (mL/kg/km) and energy cost (kcal/kg/km) was also ~3-4% (Shaw, Ingham, Fudge, & Folland, 2013) in their cohort.

4.3 RE and Swimming Performance

This study found no association between RE and 200 yard swimming performance, which agrees with Lavin's study on novice swimmers (Lavin *et al.*, 2013). In light of this, we conclude that RE is not a valid measure of swimming performance in swimmers. Thereby, it behooves further research to seek other surrogate markers for swimming performance among swimmers. Failure to demonstrate association between RE and swimming performance in a large sample size of relatively homogenous swimmers (n = 25), however, should warrant the cessation of RE investigations among swimmers, as its relevance could be poor.

Ideally, economy while swimming would have been assessed instead of running economy; our laboratory is at this time unequipped to perform cardiopulmonary testing underwater. For this reason, RE was the most accessible, similar testing method. RE, however, still bears importance on the emerging population of crossover athletes, particularly in the multi-sport arena such as triathlon, for whom running is a regular portion of their training, but still includes swimming.

A strong negative relationship was demonstrated between VO_{2max} (L/min) and 200 yard swimming performance indicating that as VO_{2max} (L/min) increases, the time to complete a 200 yard swim decreases (r= -0.84, $p < 0.05$). This is in agreement with the findings that swimmer's absolute VO_{2max} (L/min) is an important predictor of swimming performance (Butts et al., 1991). As well, this provides for insight on whether a swimmer's time trial performance should be regarded as comparable, superior, or inferior to that of their maximal aerobic capacity.

4.4 Familiarization trials for RE testing

Our investigation will inform future research on particular necessity of familiarization for investigating VO_{2max} and RE in elite swimmers. No statistically significant differences were found between familiarization and baseline sessions (see Table 3), which is strongly suggestive that swimmers, although not a population who regularly runs, do not require familiarization to a treadmill or metabolic cart. nvestigators in the future can forego familiarization and begin with baseline testing.

4.5 Day-to-day variability in RE

In light of finding no significant improvement from a CFB intervention, our investigation expanded its aims to assess the day-to-day variation in several cardiopulmonary parameters. The day-to-day coefficient of variation of 2.4% in RE (ml/kg/km) demonstrates that RE is a stable measure, even in swimmers, who are unaccustomed to running.

Other research in day-to-day variability of RE conflict with our findings, as well as with one another. Zavorsky and colleagues found that the mean day-to-day variability of RE in an elite, homogeneous male running cohort (mostly college runners) was 2.5% [mean = 196 (SD 13), range = 166 to 232 mL/kg/km] (Zavorsky, Montgomery, & Pearsall, 1998). These findings are similar to other research by Morgan *et al.*, who found the variation of RE is about 1.3% (range = 0.3 to 4.4%) in well trained runners (Morgan, Martin, Krahenbuhl, & Baldini, 1991). Pereira *et al.* investigated the day-to-day variability (the day-to-day coefficient of variation) in RE among highly-trained and moderately-trained male runners, found to be 1.8% and 2% respectively and not

statistically different ($p > 0.05$) (Pereira & Freedson, 1997). These conflicting findings suggests that the variability of RE may differ greatly in research despite a homogenous pool of subjects. Morgan *et al.* explicitly states their strict control of some testing procedures that may have contributed to their more narrow variation; these differences will be discussed more thoroughly in limitations below. Still, further research is needed to explain the differences uncovered here.

4.6 Limitations

Authors of this study recognize it has some limitations. While the results of this study bear important information on athletic testing and coaching at large, we recognize that CFB training among elite swimmers is only immediately relevant to like populations.

Subjects of this study were elite swimmers all retained by the NCAA Division I swimming team of the University of Louisville, and thus are not a randomly obtained sample. Subjects identified as Caucasian/White, and only one identified as Hispanic/Latino; race of subjects was a known delimitation among our convenience sample. Research suggests that race may substantially influence VO_{2max} (Ceaser, Fitzhugh, Thompson, & Bassett, 2013). Ceaser *et al.* found that VO_{2max} was significantly higher for Mexican Americans than for non-Hispanic Whites, with race explaining a significant component of the variance (19%, $p < 0.01$) in VO_{2max}. This piece of literature observed that the intersection of race with physical activity and degree of exercise intensity cumulatively accounted for a lot of difference in $VO_{2max.}$ In light of this, our investigation cannot be considered an ethnically diverse nor representative sample of the population.

As is true of most research conducted on athletes whose training volume vacillates seasonally, the subjects of this study underwent research at the very beginning of their pre-season training. Therefore, we tracked training volume of athletes during the study in order to account for the possibility that increase in training volume in general, not from this intervention specifically, may have affected VO_{2max} or RE. In spite of this, previous research has demonstrated that volume overload in and of itself does not affect RE (Palazzetti et al., 2005). Even still, a control group was retained in order to comparatively indicate augmentation in either VO_{2max} or RE due to training alone. While internal validity may have benefitted from an experimental design wherein subjects *only* underwent CFBH or SM intervention, it is unrealistic to the nature of an elite swimmer's training and should be considered supportive of the external validity of this research.

Findings may be limited by the periodical timing of the study. This intervention was implemented during the subjects' offseason and into the beginning weeks of preseason. Aerobic performance of swimmers has been shown to vary throughout a swimmer's training season (Perini et al., 2006). This phase of training limits relevance of results to the period of training of other swimmers.

Our failure to reproduce Lavin's findings of improvement in RE may be explained by the physiological differences in our cohort. However, the intensity of the exercise may not have been sufficient to elicit performance results in an elite swimming population (Mujika et al., 1996). Future investigations of a similar sort may consider a longer intervention, although previous research does not guarantee that increased volume will improve swimming performance (Costill et al., 1991), and therefore may also fail to affect RE.

This study incurred a limitation in procedure. Investigators did not control for shoe selection of subjects between trials. Shoe style immediately and significantly alters RE (Reeves et al., 2014; Sobhani et al., 2014). Insignificant results may be confounded by the failure to control for shoe selection. Replication of this investigation should control for shoe model in subjects between all trials. To this point, subjects frequently reported experience of shin splints while running. This qualitative observation, while beyond the analysis of statistical significance, should be considered as a contextual problem.

In conclusion, RE in swimmers has not been found to be a significant predictor of swimming performance time, nor is it changed significantly with a four week intervention of CFB training in elite swimmers. The day-to-day variability in RE (mL/kg/km), energy cost (kcal/kg/km), and VO_{2max} (L/min) was found to be between 2.4 and 3.4%. Further research of CFB training in elite swimmers to improve RE is likely not warranted, although further directions should continue to investigate RE in multisport athletes who participate both in swimming and in running.

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6.1   TABLE 1   Participant Characteristics

	Stroke-matched group (n = 13, 7 men)	Controlled Frequency Breathing group (n = 12, 7 men)	*p*-value	Combined Mean (n = 25)
Variables				
Age (yrs)	19.5 (1.3) [18 to 22]	20.1 (1.1) [19 to 22]	0.13	19.8 (1.2) [18 to 22]
Weight (kg)	78 (10) [63 to 94]	77 (11) [57 to 90]	0.71	78 (10) [57 to 94]
Height (cm)	176 (8) [162 to 189]	178 (11) [156 to 191]	0.64	177 (9) [156 to 191]
BMI (kg/m²)	25.2 (2.0) [22.6 to 29.0]	24.2 (1.7) [21.7 to 27.4]	0.19	24.7 (1.9) [21.7 to 29.0]
Body fat percentage	17 (6) [9 to 26]	15 (3) [10 to 22]	0.50	16 (5) [9 to 26]
Wing span (cm)	183 (11) [165 to 199]	184 (13) [158 to 199]	0.88	183 (12) [158 to 199]
Wing span divided by height	1.04 (.02) [0.98 to 1.06]	1.03 (0.02) [1.00 to 1.08]	0.39	1.03 (0.02) [0.98 to 1.08]
Swimming performance time	115.2 (7.3) [105.0 to 126.5]	113.7 (6.6) [104.5 to 128.9]	0.61	114.5 (6.9) [104.5 to 128.9]

Mean (SD), [range]. Non-parametric *t*-tests were used for non-normally-distributed data [age, wing span/height]. Independent *t*-tests were used for all other comparisons.

6.2   TABLE 2   Experimental design; intervention progression

	Intervention	Stroke-Matched (control)	Controlled Frequency Breathing (CFB)
Week 1	12 x 50m front crawl on 1:00 min interval	May breathe every 2-3 strokes (stroke-matched), total of 110-120 breaths per workout	May only breathe 2-3 breaths per 50m lap (controlled frequency), total of 24-30 breaths per workout
Week 2 & 3	12 x 50m front crawl on 0:55 sec interval		
Week 4	12 x 50m front crawl on 0:50 sec interval		

There were 4 sessions per week.

6.3 **TABLE 3** Cardiopulmonary data obtained from the graded exercise test to volitional exhaustion as well as running economy data

	Familiarization Trial (n = 25)	Baseline Trial (n = 25)	p-value
Variables			
VO_{2max} (L/min)	4.13 (0.77) [2.93 to 5.16]	4.12 (0.84) [2.77 to 5.39]	0.79
VO_{2max} (mL/kg/min)	52.9 (5.1) [43.2 to 60.6]	52.5 (5.5) [39.4 to 63.1]	0.39
VE_{max} (L/min)	117 (21) [75 to 148]	115 (24) [63 to 149]	0.18
RER_{max}	1.13 (0.03) [1.08 to 1.19]	1.12 (0.05) [1.01 to 1.18]	0.17
HR_{max} (beats/min)	195 (9) [174 to 209]	192 (10) [177 to 210]	0.03*
Oxygen pulse at max (mL/beat)	21.9 (4.5) [16 to 32]	22.1 (4.6) [15 to 28]	0.66
Running economy (mL/kg/km)	204 (12) [182 to 224]	201 (10) [183 to 217]	0.01*
Energy cost (kcal/kg/km)	1.01 (0.06) [0.91 to 1.13]	1.0 (0.05) [0.90 to 1.09]	0.02*

Mean (SD), [range]. Running economy and energy cost was averaged over the three running speeds (6.0., 7.0, 8.0 mph for men, and 5.5, 6.5, 7.5 mph for women). *denotes statistical significance ($P < 0.05$). While maximal heart rate, running economy, and energy cost were statistically significant between trials, the effect sizes were small and not meaningful.

6.4 TABLE 4 Cardiopulmonary data for selected variables between groups

	Mean change (SD) [95% CI]	Effect size	SRM	t-statistic	*p*-value
Stroke matched (control group) (n = 13, 7 men)					
VO$_{2max}$ (L/min)	-0.1 (0.2) [-0.2 to 0.1]	-0.07	-0.34	-0.98	0.35
VO$_{2max}$ (mL/kg/min)	-1.2 (3.1) [-3.2 to 0.9]	-0.24	-0.37	-1.23	0.25
Running economy (mL/kg/km)	-3.3 (8.5) [-8.8 to 2.1]	-0.33	-0.39	-1.35	0.2
Energy cost (kcal/kg/km)	-0.02 (.04) [-0.04 to 0.01]	-0.30	-0.38	-1.32	0.21
200 yd. swimming performance time (sec)	+1.8 (4.6) [-1.5 to 5.1]	0.28	0.38	1.22	0.26
Controlled frequency breathing (n =12, 7 men)					
VO$_{2max}$ (L/min)	+0.1 (0.3) [-0.1 to 0.3]	0.10	0.25	0.76	0.47
VO$_{2max}$ (mL/kg/min)	+1.1 (3.2) [-1.4 to 3.5]	0.25	0.19	0.56	0.59
Running economy (mL/kg/km)	+1.8 (9.5) [-5.5 to 9]	0.17	0.19	.056	0.59
Energy cost (kcal/kg/km)	+0.01 (.05) [-0.03 to 0.05]	0.16	0.19	0.58	0.58
200 yd. swimming performance time (sec)	-0.1 (1.5) [-1.2 to 1.1]	-0.01	-0.05	-0.16	0.88

Mean (SD), [95% CI]. The mean change is post-test minus pre-test values. CI, confidence interval; SRM, standardized response mean.

TABLE 5   Reproducibility in cardiopulmonary variables from the graded exercise test

	Day-to-Day Variation (%)	**Measurement Error**	**Reproducibility**	**Smallest meaningful change**
VO_{2max} (L/min)	3.4%	0.14	0.39	0.20
VO_{2max} (mL/kg/min)	3.2%	1.8	4.7	2.3
V_{Emax} (L/min)	4.6%	5.3	14.6	7.3
RER_{max}	3.0%	0.03	0.09	.04
HR_{max}	2.1%	3	9	5
Oxygen pulse at max mL/beat	7.0%	1.6	4.3	2.2
Running economy (mL/kg/km)	2.4%	4.3	11.8	5.9
Energy cost (kcal/kg/km)	2.5%	0.03	0.09	0.04

Data were pooled from both groups, n = 25. The results from familiarization trial and baseline trial. Some values were rounded to the nearest whole number.

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2006	Cum Laude graduate, High School
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2009-2010	University of Kentucky Group Fitness Instructor of the Year
2011	University of Kentucky Dept. of Campus Recreation Merit Award
2013	University of Arizona Mel & Enid Zuckerman College of Public Health "Outstanding Community Health Representative" Scholarship Recipient
2014	University of Louisville Outstanding Masters of Science Exercise Physiology Student Award for Fall 2014 Commencement Recipient

Presentations:

2008-2010	Midwest FitnessFest Fitness Conference,
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2012-2013	University of Arizona College of Public Health,
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	CPH 350: Principles of Health Education & Health Promotion
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	Guest lecturer:
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	University of Arizona Department of Campus Recreation,
	Wellness lecturer:
	"Living Pain Free"
	"Lose Weight for Good"
2014	Orangetheory® Fitness, Presenting Lecturer:
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