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Does Running Time to Fatigue at Ventilatory Threshold Predict 5-Km Run Time Performance in Female Runners?

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DOES RUNNING TIME TO FATIGUE AT VENTILATORY THRESHOLD PREDICT 5-KM RUN TIME PERFORMANCE IN FEMALE RUNNERS?

BY

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Abstract

Does Running Time to Fatigue at Ventilatory Threshold Predict 5-km Run Performance in Female Runners?

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The purpose of the study was to predict 5-km run performance from run time to fatigue at ventilatory threshold (RTF) among a heterogeneous group of female runners. The hypotheses were that RTF will predict 5-km run time and that $\dot{V}O_{2max}$ and RTF will be correlated to one another. Seventeen female runners (Mean age = 32.6 ± 8.9 yrs; $\dot{V}O_{2max}$ = 48.09 ± 3.3 $ml \cdot min^{-1} \cdot kg^{-1}$) from south Florida volunteered to take part in the study. They reported a 5-km personal best run time (Mean ± SD; 24.0 ± 2.4 min) and performed an incremental $\dot{V}O_{2max}$ test on a treadmill. Ventilatory threshold (VT) was calculated. On another day, participants performed RTF at the velocity corresponded to VT (*v*VT). RTF (Mean: 39.2 ± 15.8 min) did not predict 5-km run time (R^2 = .071, $p > .05$) and was not correlated to $\dot{V}O_{2max}$ ($r = .075$, $p > .05$). Significant correlations were demonstrated between $\dot{V}O_{2max}$ and 5-km run time (R^2 =.563, $p > .05$), and between $\dot{V}O_{2max}$ and years of experience as a runner ($r = .535$, $p < .05$). We concluded that $\dot{V}O_{2max}$, not RTF is the best predictor of 5-km performance among heterogeneous group of recreational female runners and years of training are associated with the improvement in $\dot{V}O_{2max}$.

Chapter 1

Introduction

Endurance running ability is influenced by extraneous factors such as age, gender, fitness level, quality of training, running technique, and environmental conditions, and by physiological characteristics such as percentage of type I muscle fibers, the ability to store large amounts of glycogen in the muscles and spare carbohydrate by using more fat as an energy substrate, and efficient heat dissipation (40). However, in order to predict running performance, the following physiological adaptations are usually measured: maximal oxygen uptake ($\dot{V}O_{2max}$), onset of blood lactate accumulation (lactate threshold), running economy, and ventilatory threshold (VT) (2, 3, 5, 6, 9, 10, 11, 12, 14, 20).

$\dot{V}O_{2max}$ is generally considered a useful indicator for success in endurance exercise among runners especially when the athletes are heterogeneous in their $\dot{V}O_{2max}$. It may partially explain why elite male runners, who exhibit higher values of $\dot{V}O_{2max}$ than elite female runners even when $\dot{V}O_{2max}$ is adjusted for body size differences, perform better in endurance events (14). For instance, heterogeneous values of $\dot{V}O_{2max}$ (ranging from 51.1 to 68.4 $ml \cdot kg^{-1} \cdot min^{-1}$) in a group of female runners were highly related to success in 10-km running performance (ranging from 48 to 37 min) (21). However, a poor correlation exists between $\dot{V}O_{2max}$ and performance when individuals with similar values of $\dot{V}O_{2max}$ were compared (10, 14, 44). As an example, African runners performed better than Caucasian runners in 10-km (32.8 ± 1.8 vs. 33.6 ± 2.4 min, respectively), although the two groups had similar $\dot{V}O_{2max}$ (61.9 ± 5.9 vs. 65.2 ± 7.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) (46).

Differences in endurance performance among runners who have similar $\dot{V}O_{2max}$ values can partially be attributed to differences in running economy, or oxygen consumption at a given velocity of running (11). Trained runners are more economical than untrained individuals, and among males and females with the same $\dot{V}O_{2max}$ (expressed relative to body weight), males are 14% more economical than females at a given absolute velocity (14, 37). However, running economy appears to vary even among more similarly trained runners because of differences in the runners' ability, level of training, running biomechanics, muscle fiber type, substrate utilization, and muscle power (21).

Running time to fatigue (RTF), the ability to sustain a steady state $\dot{V}O_2$ for a particular running velocity, has been associated with distance running success, especially when running at a velocity corresponding to $\dot{V}O_{2max}$, called $v\dot{V}O_{2max}$ (13, 36). RTF at $v\dot{V}O_{2max}$ was significantly correlated to 10-km running performance among male and female runners who exhibited moderately heterogeneous values of $\dot{V}O_{2max}$ (59.1-75.5 $ml \cdot kg^{-1} \cdot min^{-1}$), and males ran faster than females at $v\dot{V}O_{2max}$ (14.2 vs. 12.4 mph, respectively) (14, 38). However, the results were expected because the runners with the highest $\dot{V}O_{2max}$ were those who had highest $v\dot{V}O_{2max}$ and also performed better in the 10-km run compared to the runners with lower $\dot{V}O_{2max}$ values. Thus, the relationship between RTF and $\dot{V}O_{2max}$ correlates with performance in heterogeneous group of runners as expected. On the other hand, 10 km running performance correlated significantly with RTF at $v\dot{V}O_{2max}$, but not with $\dot{V}O_{2max}$ among well-trained endurance runners with homogeneous values of $\dot{V}O_{2max}$ (36).

RTF at $v\dot{V}O_{2max}$ may not be applicable when comparing a variety of runners. For example, recreational runners may not be able to continue running long enough at $v\dot{V}O_{2max}$ to demonstrate an oxygen uptake response equivalent to their $\dot{V}O_{2max}$ values (26). Therefore, RTF at $v\dot{V}O_{2max}$ is a useful method to set intensity of interval training sessions, rather than a strategy to predict results in distances of 10-km and longer (26, 35). As an example, Kenyan female runners, who trained at a significantly lower weekly distances than Kenyan males (127 ± 8 vs. 158 ± 13 km, respectively), compensate their lower training distance by running longer distances than males at velocity corresponding to lactate threshold (*v*LT) (10.3 ± 3.2 km for females vs. 7.8 ± 3.8 km for males). This velocity is used for long interval training for distances between 1000 to 2000m. The females also run about the same interval training distances as the male runners at or above $v\dot{V}O_{2max}$ (4.8 ± 5.5 km for females vs. 6.8 ± 3.8 km for males) for distances of 200 to 600m (5).

Blood lactate level has been particularly a good predictor for distance running performance (1, 20, 21, 42). For instance, the speed at blood lactate level of 2mM and 4mM above resting level were highly correlated to16-km pace (r = .94 and r = .91, respectively), as well as to10-km pace (r = .91 and r = .93, respectively) and with 5-km pace (blood lactate level of 4mM, r = .91) in female runners (21). On the other hand, male runners ran at a pace that was 3 to 7 m/min faster during a marathon race compared to the pace equivalent to that associated with their onset of blood lactate accumulation (OBLA) as determined during laboratory testing (20).

Time to fatigue at *v*LT has also shown to be a good predictor for endurance running performance (10, 46). For example, African runners exhibited 38% lower blood lactate concentrations and greater ability to sustain high intensity endurance exercise compared to the Caucasian athletes (10). Further, a strong correlation (r = -.85) exists between RTF at *v*LT and 10-km run among male runners at blood lactate level of 4mM (39).

Measurement of ventilatory threshold (VT), a non-linear increase in minute ventilation ($\dot{V}_E$) of oxygen, is another non-invasive method that may predict endurance performance. VT was measured at 76.1 ± 5.5% of $\dot{V}O_{2max}$ in male marathon runners who ran marathon at a pace very close to VT (79.4 ± 5.2% of $\dot{V}O_{2max}$) (22). Most studies examined the effect of different training methods, such as running intensity and frequency on VT, or the relationship between VT and LT by testing male participants (1, 24, 27, 42, 45). For instance, training for 20 min continuously at an intensity corresponding to VT for 1 to 3 days for 6 weeks, increased running duration and time to fatigue at 95% of $\dot{V}O_{2max}$ in trained male runners (27). Moreover, VT was improved in interval training corresponding to 105% of $\dot{V}O_{2max}$ rather than continuous training below VT (42). In female runners however, there is no information about VT and its use as a predictor of running performance.

The Purpose

Most studies on VT examined male participants. However, lack of information exists about RTF at VT and the performance in female runners. Therefore, the purpose of the study was to determine whether RTF at VT can predict 5-km run performance among a heterogeneous group of female runners and to determine whether RTF was associated with $\dot{V}O_{2\,max}$.

Hypotheses

It was expected that RTF at VT will significantly predict 5-km run times among female runners. It was also expected that $\dot{V}O_{2\,max}$ and RTF at VT will be significantly correlated to one another.

Significance of the Study

Most studies that sought to investigate physiological variables relating to endurance running included only male runners. When female runners were examined, it was usually to compare their performance to males when some of the variables were controlled (5, 9, 14). For instance, running economy has been compared between males and females with similar $\dot{V}O_{2max}$ values (14). Further, when only female athletes are studied, they have been mostly elite athletes (5, 8, 9, 14, 21). Research on less-trained females is scant and usually examined the effect of the menstrual cycle on performance (17, 47). Therefore, the significance of the study is by examining these performance-predictors in female runners who represent a variety of training level and extent of 5-km participation.

If the results of this study demonstrate that 5-km run is related to performance at VT, well-designed training programs that include training to improve the VT may be developed (24, 27). Further, female runners generally have not reaped the benefits of well-designed training programs because most of the studies examine males only.

Limitations

Treadmill running tests may not accurately reflect running pace during road races due to extraneous factors such as the weather (e.g., temperature, wind velocity) and terrain that may affect running time.

The menstrual cycle may affect aerobic endurance performance especially during the luteal phase when the increase in progesterone concentration causes an increase in ventilation at rest and a slight reduction in $\dot{V}O_{2max}$ (30). Because of multiple tests being performed by each participant, the menstrual cycle was not a controlled factor; therefore, some menstrual cycle effects may alter test results.

Delimitations

The participants in the study were female runners and triathletes between the age of 19 and 45 years. To qualify, they must have had experience in road races for at least one year, trained regularly in the 12 months prior, trained at least 3 times per week, had trained for and participated in a 5-km race before the study, and ran a 5-km race faster than 30 min within a year prior the study.

All participants trained regularly and had not experienced a long cessation (greater than 3 weeks) of training in the last year because of an injury or other reasons. At least 2 months of regular training was performed prior to the study if they had experienced a long cessation from running.

Assumptions

It was assumed that the participants represented the entire population of female runners in the South Florida area. Second, each participant did her best on the $\dot{V}O_{2max}$ test and on the running test to fatigue at VT. Third, the runners accurately reported their training history and personal best in 5-km. Fourth, the participants accurately reported their present menstrual status.

Definitions of Terms

- Economy of Running: the rate of oxygen consumption during a given submaximal steady-state running velocity.
- Endurance: the ability to sustain submaximal activity for a prolonged time.
- Fatigue: inability to maintain a desired running speed.
- Interval Training: a specific distance which the athlete runs for a short period of time (< 5 min) at near maximal intensity and repeats this distance several times with recovery periods in between.
- Lactate Threshold (LT): The point at which blood lactate begins to increase exponentially as intensity increases.
- Maximal Oxygen Consumption ($\dot{V}O_{2max}$): the maximal rate of oxygen consumed by the body.
- Minute Ventilation ($\dot{V}_E$): the volume of air expired and inhaled each minute.
- Steady State: a running intensity in which the majority of metabolic demand is supplied by the aerobic system, with little reliance on anaerobic metabolism.

- Tidal Volume (T_V): air volume flow during inspiration and expiration during the normal breathing cycle.
- Running Time to Fatigue (RTF): the amount of time elapsed between the start and voluntary termination of running at a steady state velocity.
- Ventilatory Threshold (VT): the point at which pulmonary ventilation disproportionately increases relative to increased oxygen consumption ($\dot{V}_E / \dot{V}O_2$) without a concomitant change in ($\dot{V}_E / \dot{V}CO_2$).

Chapter II

Literature Review

Introduction

The purpose of the study was to determine whether RTF at VT can predict 5-km run performance among heterogeneous group of female runners and to determine whether RTF was associated with $\dot{V}O_{2\,max}$. It was expected that RTF at VT will significantly predict 5-km run times among female runners. It was also expected that $\dot{V}O_{2\,max}$ and RTF at VT will be significantly correlated to one another.

Successful performance in competitive distance running in heterogeneous group or runners is related primarily to the athlete's maximal oxygen capacity ($\dot{V}O_{2max}$), which distinguishes between highly-trained and less-trained individuals. However, among a homogenous group of runners where relatively small differences in performance exist, $\dot{V}O_{2max}$ values are similar (6, 11, 20). On the other hand, other physiological characteristics, such as lactate threshold (LT) and running economy, were shown to be important predictors of performance among homogeneous and heterogeneous runners (10, 13, 14, 20, 39, 46).

Running time to fatigue (RTF) at $\dot{V}O_{2\,max}$ ($v\dot{V}O_{2max}$) and at LT (*v*LT) were offered as better predictors than either $\dot{V}O_{2max}$ or running economy at a submaximal intensity in a homogeneous group of trained runners, but not in less-trained runners (6, 13, 26). Elite male and female runners did not differ in RTF at $v\dot{V}O_{2max}$ (376 ± 118 vs. 421 ± 129 sec, respectively), although they demonstrated different values of $\dot{V}O_{2max}$ (77.7 ± 6.4 vs. 63.2 ± 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) and velocities (5.8 ± .3 vs. 4.8 ± .2 $m \cdot s^{-1}$, respectively) (3).

The ventilatory threshold (VT) is associated with the exponential rise in ventilation with increasing intensities. Compared to $\dot{V}O_{2max}$, LT and running economy, VT has not been studied much as a potential predictor of performance. However, VT may be related to performance in runners. For instance, VT occurred at a similar percentage of $\dot{V}O_{2max}$ as that occurring during marathon race in a group of male runners (76.1 ± 5.5% vs. 79.4 ± 5.2% of $\dot{V}O_{2max}$, respectively) (23). Less is known about performance at VT for shorter distances in particular regarding running time to fatigue at VT.

Most studies that investigated performance predictors in runners included only male participants. Only handful of these studies examined VT as a performance variable (1, 23, 24, 28, 31, 42). When running performance was studied in females, it was usually by using elite runners of to examine the effect of the menstrual cycle on $\dot{V}O_{2max}$ and running performance (16, 17, 30, 45). As a result, there is very little information regarding running performance in less trained female athletes and even less in known about VT in female runners.

Prediction of Performance

Many factors have been shown to influence distance running performance. Probably the single most commonly used method to assess performance is the test of maximal oxygen consumption ($\dot{V}O_{2max}$) specifically in group of athletes who are heterogeneous in terms of $\dot{V}O_{2max}$. However, unlike the $\dot{V}O_{2max}$ test, other performance predictors such as LT, running economy, and VT may be more appropriate for endurance athletes who compete at submaximal intensities rather than at 100% of $\dot{V}O_{2max}$ (4, 8, 10, 11, 14, 20).

Running economy and LT have been shown to be even better predictors than $\dot{V}O_{2max}$ when a group of male and female athletes with heterogeneous values of $\dot{V}O_{2max}$ were tested (8, 11, 14, 20, 21). In addition, the relationship between running economy and the velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) and at LT (*v*LT) were determined to be better predictors in various distances (3, 19, 20). Successful runners are those who are able to sustain a race pace while utilizing the largest $\dot{V}O_2$ and avoiding a marked rise in blood lactate. Therefore they were able to extend RTF and perform better (20, 21, 46).

Most research examined the correlation between $\dot{V}O_{2max}$, running economy, RTF and ventilatory threshold to running performance in male runners. However, lack of information exists in relation to female runners, and most studies on female runners include elite runners who are more homogeneous in their running performance.

$\dot{V}O_2$ max

The maximal aerobic capacity ($\dot{V}O_{2max}$) has long been associated with success in endurance exercise, its increases endurance training. In addition, $\dot{V}O_{2max}$ depends on the initial fitness level, but more important the quality of training (40).

In group of runners demonstrating a wide range of $\dot{V}O_{2max}$ values, an incremental test to exhaustion is the usual method to determine $\dot{V}O_{2max}$. In this case, $\dot{V}O_{2max}$ is a strong predictor of performance. For instance, among four groups of runners, the elite male runners who ran 10 km in less than 30 min, demonstrated the highest $\dot{V}O_{2max}$ (75.6 ± 3.2 $ml \cdot kg^{-1} \cdot min^{-1}$). The sub-elite runners who ran 10-km faster between 35 min and 30 min, had a $\dot{V}O_{2max}$ of 70.5 ± 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$, the moderately-trained runners who ran 10 km between 36 to 46 min showed values of 59.3 ± 4.1 $ml \cdot kg^{-1} \cdot min^{-1}$, and last were the untrained individuals who had $\dot{V}O_{2max}$ of 51.4 ± 3.9 ml·kg^{-1}·min^{-1} (37). Another study that examined three groups of female runners of different ages (Group I, mean:30 ± 1, Group II, mean: 42 ± 1 and group III, mean: 52 ± 1 yrs) showed that the value of $\dot{V}O_{2max}$ was associated with the pace over 10-km run. Group I demonstrated the highest mean $\dot{V}O_{2max}$ (57.6 ± 0.9 ml·kg^{-1}·min^{-1}) and the fastest 10-km pace (265 ± 3 m/min) compared to group II and III (Mean $\dot{V}O_{2max}$: 54.1 ± 1.0 and 45.0 ± 1.4 ml·kg^{-1}·min^{-1}, respectively; Mean10-km run pace 244 ± 3 and 210 ± 4 m/min, respectively) (18). Farrell showed that the onset of blood lactate accumulation (OBLA) is closely related to marathon race pace in a group of experienced marathon runners who demonstrated heterogeneous values of $\dot{V}O_{2max}$ (range from 46.3 to 73.7 ml·kg^{-1}·min^{-1}) (20). However, $\dot{V}O_{2max}$ and the capacity of maintaining a large $\dot{V}O_2$ during the race were related to the purpose of maintaining low blood lactate during the race ($r \geq .83$ and $r \geq .91$, respectively). However, in a homogeneous group of highly–trained 10-km runners (10-km time range from 30.52 to 33.55 min) a small non-significant correlation was shown between $\dot{V}O_{2max}$ (range from 77.74 to 73.72 ml·kg^{-1}·min^{-1}) and race time ($r = -.12$, $p = .35$) (11). The author determined that among highly-trained and experienced runners of comparable ability and similar $\dot{V}O_{2max}$, running economy account for the variables in 10-km race performance.

Running Time to Fatigue at a Given Percentage of $\dot{V}O_2$ max

Among runners who are relatively homogeneous in $\dot{V}O_{2max}$, the velocity of running at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$), may be a better predictor for success in endurance events (2, 3, 6). For instance, the reproducibility of running time to fatigue at $v\dot{V}O_{2max}$ and the correlation between $v\dot{V}O_{2max}$ and performance over 3-km and 21.1-km was examined in male runners with homogeneous $\dot{V}O_{2max}$ values (range from 65.0 to 68.1ml·kg^{-1}·min^{-1}) during a 1-week interval (6). A significant correlation was only observed between RTF at $v\dot{V}O_{2max}$ and LT expressed in $\dot{V}O_{2max}$ (r = .745) and the speed sustained over a 21.1-km race expressed in km/hr (r = .719). The correlation between performance and blood lactate concentration was shown in runners with similar $\dot{V}O_{2max}$ values who ran at $v\dot{V}O_{2max}$ (36). The participants ran a 10-km race; then $\dot{V}O_{2max}$ was measured during an incremental test on a treadmill. They also performed a 4 min maximal test to measure running economy and blood lactate concentration. The correlation between 10-km run time and $\dot{V}O_{2max}$ was only r = - .45, and the correlation between 10-km running time and running economy (expressed in ml·kg^{-1}·min^{-1}) was r = .64. However, high correlation was demonstrated between 10-km running time and $v\dot{V}O_{2max}$ (r = -.87), and the correlation between $v\dot{V}O_{2max}$ and 10-km running time was highly related to the treadmill velocity at blood lactate concentration level of 4mM (r = -.82).

Similar results were demonstrated between African male runners and Caucasian male runners who had the same values of $\dot{V}O_{2max}$ (10, 46). The African runners had a significantly greater ability to sustain 92% of $v\dot{V}O_{2max}$ for longer time than the Caucasian runners (7:56 ± 3:45 vs. 3:57 ± 2:05 min, respectively) (46). Further, the black African runners ran significantly faster than the Caucasian runners over distances greater than 5-km, such as in 21.1-km, which the black runners ran at 20.1 ± 0.7 km/h and the Caucasian runners ran at 18.7 ± 0.6 km/h (10).

$v\dot{V}O_{2max}$ has been show to be a good predictor for middle-distances (1500m) and for long distances (10-km and 21-km) running performance (2, 6). Morgan and colleagues found a significant relationship (r = -.78) between 10-km run time and $v\dot{V}O_{2max}$ in well-trained male runners who demonstrated moderately-heterogeneous values of $\dot{V}O_{2max}$ (59.1-75.5 $ml \cdot kg^{-1} \cdot min^{-1}$) (36). An even higher correlation (r = -.87) was found between 10-km running performance and $v\dot{V}O_{2max}$ in runners who showed similar values for $\dot{V}O_{2max}$ (64.8 ± 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$) (38).

However, $v\dot{V}O_{2max}$ may not be an accurate predictor for endurance events when runners who race at different distances are compared. For example, middle-distance runners who use to train at $v\dot{V}O_{2max}$ ran to fatigue at $v\dot{V}O_{2max}$ 23.8% longer compared long distance runners, although both groups demonstrated similar $\dot{V}O_{2max}$ values (2). Further, the $v\dot{V}O_{2max}$ may not be a good predictor for performance in less-trained runners (26). For instance, a $v\dot{V}O_{2max}$ test performed by recreational runners ($\dot{V}O_{2max}$: 51.1 ± 5.8 $ml \cdot kg^{-1} \cdot min^{-1}$) showed that 5 of the 11 runners did not achieved an oxygen uptake values during the run that were equivalent to the value previously recorded during two incremental tests (26).

For these reasons, the $v\dot{V}O_{2max}$ is more appropriate for prescribing training intensities to improve running time to fatigue. For instance, the ability of elite triathletes to sustain $v\dot{V}O_{2max}$ was measured in three different run duration (35). The First session was three sets of 30 sec run at 100% $v\dot{V}O_{2max}$ alternated with 30 sec run at 50% $v\dot{V}O_{2max}$. The second session was three sets of 60 sec at 100% $v\dot{V}O_{2max}$ alternated with 30 sec run at 50% $v\dot{V}O_{2max}$. The third session was half of the time they ran at 100% $v\dot{V}O_{2max}$ alternate with half of the time of 100% $v\dot{V}O_{2max}$ but performed at 50% $v\dot{V}O_{2max}$. Time sustained above 95% and 90% of $\dot{V}O_{2max}$ was compared between the three intermittent runs. The 30 sec interval intermittent running led to a significantly shorter running time over 90% $\dot{V}O_{2max}$ (149 ± 33 sec) compared to the 60 sec intervals (531 ± 187 sec) and the RTF at half time 100% and 50% of $v\dot{V}O_{2max}$ (487 ± 176 sec). The authors suggested that athletes who ran at 60 sec intervals and at RTF at half time 100% and 50% of $v\dot{V}O_{2max}$ may need longer time to reach 90% of $\dot{V}O_{2max}$ and thus, their $\dot{V}O_{2max}$ values remained lower during the 30 sec intervals. Therefore, they may benefit of interval training for 60 sec or more.

Running Economy

Running economy is defined as the oxygen uptake at a given absolute exercise intensity (14, 20, 37). Better running economy (a lower $\dot{V}O_2$) is considered to be an advantage to endurance performance because it indicates the runner can perform that work load at a lower energy cost (lower percent of $\dot{V}O_{2max}$).

Among trained runners who are homogeneous in their $\dot{V}O_{2max}$, differences in running economy may be the reason for better running performance (11, 21). Highly trained 10-km runners (mean $\dot{V}O_{2max}$ 71.7 ± 2.8 $ml \cdot kg^{-1} \cdot min^{-1}$) demonstrated a low, correlation (r = -.12) between $\dot{V}O_{2max}$ and 10-km running performance. On the other hand, a high correlation was found between three submaximal speeds (241, 268, and 295 $m \cdot min^{-1}$) that were performed for 6 min each with 3 min rest between the runs and running performance at $\dot{V}O_2$ of 44.7, 50.3, and 55.9 $ml \cdot kg^{-1} \cdot min^{-1}$,respectively (r = .83, .82, and .79, respectively) (11). Running economy at three treadmill speeds (196, 215, and 241 $m \cdot min^{-1}$) was correlated to running performance for 5-km (r = - 0.40) and for 16-km (r = - 0.63) in a moderately homogeneous group of female runners ($\dot{V}O_{2max}$ range from 51.70 to 68.40 $ml \cdot kg^{-1} \cdot min^{-1}$) (21). These studies suggested that running economy may be more important at longer distances.

Running economy is influenced by several biomechanical factors. An uneconomical runner, for instance, expends more energy through vertical movements during running, and runners who train on a flat terrain will be less economical on hilly terrain compared to runners who train on hilly terrain (40). Other influences are related to the weight of the shoes and clothing worn during running, stride length while and frequency and changes in body weight (40).

Different types of training can affect efficiency in a specific sport. For example, highly trained male triathletes were more efficient during cycling compared to running because they had a higher relative volume of training in cycling (44). In addition, running economy appears to be speed-specific so that marathon runners tend to be more economical than middle-distance runners at a marathon pace. On the other hand, over near maximal velocities at distances of 800-1500m, marathon runners are less economical compared to middle-distance runners who train more frequently at high velocities over these distances (14).

Different training methods were suggested to improve running economy (22). For instance, a group of recreational runners trained 3 times per week for 6 weeks (22). The group was divided into three distance training groups: (1) continuous distance running until exhaustion (Mean speed: 15 $km \cdot h^{-1}$), (2) long intervals consisting of 4-min run with 2-min rest repeated four to six times (Mean speed: 16.6 $km \cdot h^{-1}$), (3) and short intervals runs consisting of 15 sec run with 15 sec rest repeated 30 to 40 times (Mean speed: 20.4 $km \cdot h^{-1}$). In addition the runners ran one to three individual training sessions per week at a pace lower then 65% of HRmax. $\dot{V}O_{2max}$ and RTF at 87% of $\dot{V}O_{2max}$ were performed before and after the six-week training program. Running economy was significantly improved by 3.1% in the long distance run group and by 3.0% in the long intervals group. There was no significant improvement after short intervals training. The improvement in running economy was significantly correlated (r = 0.77) to a reduction of 11.1 $L \cdot min^{-1}$ in $\dot{V}_E$ during the RTF at 87% of $\dot{V}O_{2max}$ (21).

Lactate Threshold

Lactate threshold (LT) is the point at which blood lactate level rise exponentially with increase intensities. LT is a powerful predictor for endurance performance (20, 39, 45). For instance, the relationship between 10-km running velocity and three running at LT velocities was examined in a heterogeneous group of male and female runners (mean $\dot{V}O_{2max}$ for the whole group: 55.1 ± 8.8 $ml \cdot kg^{-1} \cdot min^{-1}$) (39). The participants ran two 10-km time-trials on a track; they also performed an incremental test on a treadmill to assess their blood lactate accumulation level and an additional incremental treadmill test to measure $\dot{V}O_{2max.}$ Three LT velocities were determined. First, the LT velocity at which blood lactate increased by ≥1$mM \cdot L^{-1}$ (LT_1) to the x-axis was examined. Secondly a straight line was drawn from the minimum and the maximum lactate points, the velocity associated with the widest point between the lactate curve and the straight line was determined as the second velocity (LT_D). The third LT velocity was that at which blood lactate reached 4$mM \cdot L^{-1}$ (LT_4). Running velocity at LT_D was the most strongly correlated to 10-km velocity (r = .86). Significant correlation with 10-km velocity was also shown with LT_1 and LT_4 (r = .78, and r = .83 respectively) (39).

An increase in oxidative capacity through training, improves LT by increasing the ability to exercise at a higher intensity with less accumulation of blood lactate (1, 24). Trained male runners who participated in an 8-wk training program which included increased running intensities for 3 days per week, demonstrated blood lactate levels of 2.5 and 4mM at a higher percentage of $\dot{V}O_{2max}$ (77.5% and 85.4%, respectively) after training intervention compared to pre-training (73.6% and 81.4%, respectively) (1). LT expressed in ml/min was increased in untrained individuals who underwent a training program that was consisted of three weeks, six days/wk for 30 min at work rate of 70 to 80% of $\dot{V}O_{2max}$ (24). LT was measure during a $\dot{V}O_{2max}$ test at 1,643 ± 127 ml/min and was increase significantly every week of the training program as follow: week I to 1,705 ± 178 ml/min, week II to 1,978 ± 313, and week III to 2,125 ± 235 ml/min.

Similar results were shown with sub-elite male runners (Mean $\dot{V}O_{2max}$: 69.5 ± 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$) who showed significant correlation (r = 0.745), between RTF at $\dot{V}O_{2max}$ and LT of 3-5mM (6). The runners who displayed a marked increase in lactate concentration at a later stage during an incremental test were those who sustained $v\dot{V}O_{2max}$ for longer time, and they also performed better in 21.1-km than the runners who had an earlier accumulation of blood lactate and slower running time at $v\dot{V}O_{2max}$.

Farrell and colleagues suggested that the lactate level achieved during running on a treadmill may underestimate the energy cost related to road race conditions (20). Male runners were examined in a series of 8 runs for 10 min each at submaximal intensities that correlated to the runners' 3.2, 9.7, 19.3 km, and marathon pace. Then the runners participated in road races with similar distances. The strongest significant correlation ($r \geq .91$) was shown between any given distance and onset of blood accumulation (OBLA) on a treadmill. However, during the marathon race the runners ran at 3 to 7 m/min above the OBLA velocity attained on a treadmill. The reasons may be due to the runners' muscle fibers composition or running economy which may contribute to the ability to sustain a given velocity without significant accumulation of blood lactate.

Trained long distance female runners were tested to examine the relationship between road races and blood lactate level (21). A high significant correlation was demonstrated between 10-miles, 10-km and 5-km run time and lactate accumulation levels of 2 and 4mM on a treadmill ($r = .84$ to $.94$).

Ventilatory Threshold

Ventilatory threshold (VT) is the point reached during progressively increasing exercise intensity after which $\dot{V}CO_2$ increases at a faster rate than $\dot{V}O_2$ in response to increasing intensity (31). It is also characterized by an increase in the ventilatory equivalent for $\dot{V}O_2$ ($\dot{V}_E / \dot{V}O_2$) without a concomitant increase in the ventilatory equivalent for $\dot{V}CO_2$ ($\dot{V}_E / \dot{V}CO_2$) (28). The VT occurs as a result of interactions between oxygen transport and utilization, type of activated muscle fibers, oxidative enzyme levels and substrate utilization (14). In addition, the percent of $\dot{V}O_{2max}$ at which VT occurs is an indicator of endurance performance (1, 2, 13).

Ventilation is controlled by neural and humoral mechanisms (34). The neural pathway is located in the medulla and the hypothalamus in the brain and affects the duration and the intensity of the inspiration cycle. The humoral pathway stimulates the neural units via changes in the chemical state of the blood, such as arterial partial pressure of oxygen (PO_2) and carbon dioxide (PCO_2), level of blood lactate, and blood temperature.(42) At the beginning of exercise, the cerebral cortex stimulates the medulla to increase ventilation abruptly; this increase in ventilation is called hyperpnea (31, 32). The increase in ventilation is accomplished initially by an increase in tidal volume (TV), which enhances the volume of air in the alveoli beyond the volume in the anatomical dead space. A steady increase in TV and, eventually, breathing rate will match the increased metabolic needs as exercise intensity increases. At high enough intensities (35% to 60% $\dot{V}O_{2max}$) TV will plateau while breathing rate and ventilation continue to increase with increasing intensity. This increase in $\dot{V}_E$ corresponds to a small elevation in blood lactate beyond low exercise intensity level of 1mM, and RER values between .85 and .90 (33).

As work rate increases, blood lactate progressively rises. This leads to an exponential rise in ventilation, which can be explained by the bicarbonate system; consisting of lactate, sodium bicarbonate, sodium lactate, and carbonic acid (H_2CO_3). The hydrogen ions (H^+) derived from the production of lactate are responsible for the increase of both H_2CO_3 and CO_2, through the carbonic anhydrase reaction:

$$H^+ + HCO_3 \leftrightarrow H_2CO_3 \leftrightarrow H_20 + CO_2$$

The ventilation control mechanism maintains the homeostasis of PCO_2 and H^+, thus an increase in H^+ and PCO_2 results in hyperventilation (14).

Hyperventilation during exercise is not necessarily due to an increase in blood lactate concentration. For instance, Hagberg and colleagues examined the ventilatory response in patients lacking the enzyme phosphorylase in their muscles (McArdle's disease), which causes an inability to produce lactate during exercise (25). During a $\dot{V}O_{2max}$ test on a cycle ergometer, blood lactate increased in healthy individuals to 8.30

± 1.61 mM at about 65-75% of $\dot{V}O_{2max}$, while mcArdle patients exhibited no blood lactate response above resting level. Further, during exercise pH decreased significantly in the healthy participants, but not in the McArdle's patients. However, no differences were shown in ventilatory response between the two groups indicating that the increase in ventilation in McArdle's disease is not associated with blood lactate level.

Farrell and colleagues also investigated whether the increase in $\dot{V}_E / \dot{V}O_2$ during exercise is mediated by a rise in blood H^+ level (19). Two groups of healthy males participated in the study. The experimental group performed two 3-min sessions of high intensity exercise on a cycle ergometer in order to increase blood lactate level and decrease blood pH. In addition they performed a $\dot{V}O_{2max}$ test on a cycle ergometer. The control group performed only the $\dot{V}O_{2max}$ test. The experimental group demonstrated a significant increase in $\dot{V}_E / \dot{V}O_2$ compared to the control group (57.3 ± 8.53 vs. 45.14 ± 13.95, respectively). At the point at which $\dot{V}_E / \dot{V}O_2$ rose, the experimental group showed significantly higher blood lactate, lower venous blood pH, and higher blood level of HCO_3. However, $\dot{V}_E / \dot{V}O_2$ occurred at the same work rate and $\dot{V}O_2$ in both treatments, suggesting that a rise in H^+ concentration is not responsible for the abrupt increase in ventilation during exercise (19).

Differences between an increase in ventilation and blood lactate accumulation were also demonstrated after 3 weeks of training in untrained individuals. They cycled for 30 min at 70-80% of $\dot{V}O_{2max}$ 6 d/wk, and had an increase in $\dot{V}_E / \dot{V}O_2$ before a rise in blood lactate concentration during incremental exercise on cycle ergometer (24). Further, after the training program LT was significantly increased with no significant increase in

VT. Despite the dissociation between LT and VT as a result of training, the two parameters were still highly correlated post-training (r = 0.86).

CO_2 is a powerful ventilatory stimulant and the rise in the PCO_2 results in increase of $\dot{V}_E$ by 10% to 30% during exercise (33). The increase in exercise intensity results in an increase in catecholamine flow and a rise in body temperature that causes a linear increase in $\dot{V}_E$ and an increase in carbon dioxide output ($\dot{V}CO_2$), including an abrupt increase in the respiratory exchange ratio (RER) (15).

Ventilatory Threshold as a Performance Predictor

Successful performance in distance runs does not only depend on $\dot{V}O_{2max}$, running economy and LT, but also in the ability to sustain a high fractional utilization of $\dot{V}O_{2max}$. Male marathon runners were examined to assess the correlation between an endurance index which is the relationship between % $\dot{V}O_{2max}$ and ventilatory threshold (23). The runners performed an incremental test on a treadmill to determine VT and two weeks later ran a marathon race. The fractional utilization of $\dot{V}O_{2max}$ was computed from the runners' average running speed during the marathon and the relationship between the marathon running speed and $\dot{V}O_2$ observed on a treadmill. A significant high correlation (r = .853) was found between the endurance index and the average % $\dot{V}O_{2max}$ at VT (76.1 ± 5.5% of $\dot{V}O_{2max}$). However, this value of $\dot{V}O_2$ was lower than the $\dot{V}O_2$ value demonstrated by the runners during the marathon (79.4 ± 5.2% of $\dot{V}O_{2max}$).

Prediction of performance using three methods to determine VT was examined using trained cyclists during a $\dot{V}O_{2max}$ test and a 40-km time trail on cycle ergometer in two different months (February and September) (32). The most significant and consistent predictor for 40-km cycling time trial was the $\dot{V}_E / \dot{V}O_2$ method (Feb: r = .80, Sep: r = .81). However, significant results were also demonstrated for the V-slope method which is the ratio between $\dot{V}O_2$ vs. $\dot{V}CO_2$ (Feb: r = 0.79, Sep: r = .81), RER value of .95 (Feb: r = .73, Sep: r =.58), and RER value of 1.00 (Feb: r = .75, Sep: r = .74).

Similar results were demonstrated by elite cyclists who performed a time trial for 5 km covered 8 times (24). The V-slope method and the $\dot{V}_E / \dot{V}O_2$ method were significantly correlated to (V-slope: r = -.82, and $\dot{V}_E / \dot{V}O_2$ (r = -.81). The V-slope method however, was a better predictor for assessing HR values during the time trail (r = .93) compared to $\dot{V}_E / \dot{V}O_2$ method (r = .90).

Studies to predict performance at VT are scant and examined male athletes. However, no information was found about prediction of performance at VT for female athletes.

Measuring Ventilatory Threshold

Measuring VT is non-invasive and depends on the subjectivity and the experience of the observers, compared to the invasive and more conclusive method for measuring blood lactate accumulation.

Three methods have been used to measure VT (28, 31, 32, 43). First, the V-slope method which relies on the identification of a clear rise of $\dot{V}CO_2$ compared to $\dot{V}O_2$ (31, 32). Another method uses a respiratory exchange ratio (RER) level of .95 and 1.00 (32). During rest the RER level is normally .7 to .8, but with increases in exercise intensity, CO_2 rises, which results in an increase of RER. The third method is the identification of a systematic increase in the ventilatory equivalent for O_2 ($\dot{V}_E / \dot{V}O_2$) without a concomitant increase in the ventilatory equivalent of CO_2 ($\dot{V}_E / \dot{V}CO_2$) (24, 28, 31, 32).

The validity and the reliability of the methods to determine VT were determined during a 40-km time trial performed by male cyclists (30). Each method has been successfully used to predict performance, but the $\dot{V}_E / \dot{V}O_2$ method appears to be the better of the three. However, after testing elite cyclists in eight time trials for 5-km each, Hoogeveen and colleagues recommended using the V-slope method (r = .82) for training regulation. Still, the $\dot{V}_E / \dot{V}O_2$ was also significantly correlated (r = .81) to the performance at the time trial, but insignificant correlation was found with RER at .95 and 1.00 (28).

The validity of the visual inspection to detect a rise $\dot{V}_E / \dot{V}O_2$ with no concomitant increases in $\dot{V}_E / \dot{V}CO_2$ was examined in an experiment that used observers with a variety of experience: very experienced observers, less experienced, and novice observers who learned how to determine the VT in one hour (44). The results showed a high correlation coefficient (r = .94) between the three observer groups. In addition, the reproducibility tests showed significant coefficient correlation between the first and the second test (r = .97), which indicates a good reliability of the criterion.

Although no significant differences exist between the $\dot{V}_E / \dot{V}O_2$ and the V-slope methods for identifying VT , most research and also this study assessed the VT by graphing the results of the ventilatory equivalent for oxygen ($\dot{V}_E / \dot{V}O_2$) and for CO_2 ($\dot{V}_E / \dot{V}CO_2$) (1, 24, 27, 43). The point where $\dot{V}_E / \dot{V}O_2$ exhibited a systematic increase without an accompanying rise in the ventilatory equivalent for CO_2 was determined as the VT. In addition, an abrupt increase in $\dot{V}_E$ was also used to confirm this point.

Training Effect on Ventilatory Threshold

Exercise induces a number of beneficial physiological effects in skeletal muscle such as increased density of mitochondria, oxidative enzyme content, and enhanced capillary density. These changes increase the capacity for aerobic exercise and delay the appearance of OBLA and lead to a lower ventilatory response at a given submaximal exercise intensity and increased VT, thus improving endurance performance (1, 10, 20, 24, 40, 42, 45, 46).

It is well known that an increase in $\dot{V}O_{2max}$ usually occurs as a result of endurance training in untrained people. However, trained athletes may show little or no further improvement in $\dot{V}O_{2max}$ with continued aerobic training (14). Therefore, trained runners train to improve other performance parameters. For instance, the effect of high-intensity training on VT was studied using long distance runners during 8 weeks of increased running intensities 3 days per week while maintaining usual running intensities on the other days (1). Interval running was performed at 90-95% of HRmax and two Fartlek runs for distances of 6-10 miles at around a 10-km race pace. The $\dot{V}O_{2max}$ and VT did not significantly change after training. On the other hand, lactate concentrations were lower at 85-95% of $\dot{V}O_{2max}$ after training than before the training program.

The hypothesis that VT occurs at lower exercise intensity than LT in untrained people was also examined (45). The participants, trained cyclists and untrained males, performed an incremental test on a cycle ergometer. The trained cyclists' VT and LT occurred at similar intensities (68.6% of $\dot{V}O_{2\,max}$ and 68.8% of $\dot{V}O_{2max}$, respectively). In contrast, the untrained VT occurred at a lower percent of $\dot{V}O_{2\,max}$ than did the LT (51.4% of $\dot{V}O_{2max}$ and 61.6% of $\dot{V}O_{2max}$, respectively). The reasons for the differences between trained and untrained, were attributed to a faster rate of lactate diffusion from muscles to the blood in the trained athletes compared to the untrained participants. The trained athletes demonstrated a higher percentage of slow twitch muscle fibers than fast twitch fibers. The trained athletes also had a higher cardiac output and blood flow to the muscles at OBLA compared to their untrained counterparts. Therefore, the humoral stimulation of exercise hyperventilation by excess CO_2 is more closely related with the appearance of increasing level of lactate in the blood for trained athletes.

Geasser and Poole examined the relationship between LT and VT as a result of continuous or interval training performed 3 d/wk for 8 weeks (24, 42). The participants were untrained males. In the first study the participants were randomly assigned to one of three training groups (42). The first group trained with continuous exercise for 55 min at 50% of $\dot{V}O_{2max}$, and blood lactate level of less than 2mM. The second group trained 35 min at 70% of $\dot{V}O_{2max}$ at blood lactate $\geq$ 4mM, and the third group performed 10 repetitions of 2 min intervals at 105% of $\dot{V}O_{2max}$ with 2 min of rest. All groups demonstrated a significant increase in $\dot{V}O_{2max}$ and no differences were shown between groups. Ventilation at VT was increased significantly for all three groups, but the increase was greatest in the group who trained using intervals. The LT increased but was not significantly different between groups. The main finding of the study was that high intensity interval training had a greater effect on VT than LT compared to the effect of lower intensity training. The second study by Gaesser and Poole examined the hypothesis that LT may increase during the first 3 weeks of endurance training without any concomitant change in VT when training is performed at steady state intensities (24). Untrained males and females exercised on a cycle ergometer for 3 weeks, 6 d/wk for 30 min at 70% to 80% of $\dot{V}O_{2max}$. LT increased from pre-training to post-training by 29.3% after 3 weeks. In addition, significant reductions were observed, during a $\dot{V}O_{2max}$ test, after one week of training in $\dot{V}CO_2$, $\dot{V}_E$, $\dot{V}_E / \dot{V}O_2$, and HR. In contrast, VT did not change significantly after the 3 weeks. Based on these studies the authors suggested that interval training enhances VT and that the changes in VT were not related to changes in $\dot{V}_E$. Further, the delay in the onset of blood lactate accumulation was not linked to $\dot{V}_E / \dot{V}O_2$. These results indicate that improvements in LT and VT arose from different mechanisms.

The importance of exercise type on VT was shown in triathletes who were tested to find differences between cycling and running modalities (44). Incremental tests were performed on a cycle ergometer and treadmill. Run $\dot{V}O_{2max}$ was significantly higher than cycle $\dot{V}O_{2max}$ (75.4 ± 7.3 and 70.3 ± 6.0 ml·kg^{-1}·min^{-1}, respectively). The VT on the treadmill occurred at a significantly higher level of oxygen uptake compared to the VT on the cycle ergometer (53.9 ± 3.8 vs. 46.9 ± 4.3 ml·kg^{-1}·min^{-1}). When expressing as percent of $\dot{V}O_{2max}$, the VT was significantly different between cycle ergometer and treadmill (66.8 ± 3.7% $\dot{V}O_{2max}$ vs. 71.9 ± 6.6%, respectively).

The Female Runner and Running Performance

Prediction of running performance for highly-trained female runners were examined using parameters such as $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, LT, and running economy (4, 14, 21, 27). However, a lack of information exists about prediction of performance at VT for female runners.

A performance-related characteristic that distinguishes male runners from female runners is higher $\dot{V}O_{2max}$ in males (14). The main factor associated with these differences in $\dot{V}O_{2max}$ between genders is fat free body mass. Men had a higher body weight than the women (65.3 ± 4.3 vs. 56 ± 5.5 kg, respectively) whereas, the women had more than twice the percent of body fat than the men (14.9 ± 2.4% vs.7.6 ± 1.7%) (3). For instance, $\dot{V}O_{2max}$ was significantly higher in elite male runners who were ranked at the same competitive level as the female runners according to the International Amateur Athletic Federation (77.7 ± 6.4 vs. 63.2 ± 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$,respectively). As a result, the males had higher $v\dot{V}O_{2max}$ than the females (5.8 ± 0.3 $m \cdot s^{-1}$ vs. 4.8 ± 0.2 $m \cdot s^{-1}$, respectively) (3). Likewise, male runners demonstrated faster running velocities than female runners at three different blood lactate concentration level of 1 mM, 4mM, and the middle point of the curve between 1 and 4 mM (39).

In absolute velocities males runners have demonstrated 14% lower $\dot{V}O_{2max}$ at a given running velocity than female runners (14). On the other hand, in relative intensities of effort (% $\dot{V}O_{2max}$), the differences in economy are only 1-2%. Further, in terms of relative intensity, lactate concentration of 4mM occurred at a similar percentage of $\dot{V}O_{2max}$ for female and male runners (87.1 vs. 85.5 % $\dot{V}O_{2max}$, respectively). On the other hand, running economy did not significantly differ between female and male runners at a velocity of 16.1 km per hour when $\dot{V}O_{2max}$ was scatted to .75 exponents. Gender differences in % $\dot{V}O_{2max}$ at a 10-km race pace (males: 92.6 ± 0.8% $\dot{V}O_{2max}$, females: 93.7 ± 1.9% $\dot{V}O_{2max}$) was also insignificant (5).

These results are similar to the results of a study that examined bioenergetic characteristics in elite female and male middle-distance runners (3). There were no significant differences in RTF at $v\dot{V}O_{2max}$, OBLA express as %$v\dot{V}O_{2max}$ or running economy at 14-km·h. Interestingly, running velocity at 1500m was predicted by $v\dot{V}O_{2max}$, velocity at OBLA and by RTF at 110% of $v\dot{V}O_{2max}$ in male runners, but not in females. The authors suggested that the study did not find a significant predictor for the female runners in that some of the 1500m female runners were more 800-1500m specialists and the others were more 1500-5000 runners (3).

Differences in physiological or performance characteristics between men and women can be partially explained by the typically higher training volumes in males (4, 5). For instance, elite male marathon runners averaged longer weekly distances than elite female runners (206 ± 26 km vs. 166 ± 11 km, respectively) (4). In addition males ran more km per week at 3-km and 10-km race paces than females (17.8 ± 1.8 km vs. 12.4 ± 2.3 km respectively).

Similarly, Kenyan female runners averaged lower weekly running distances compared to the males (127 ± 8 km vs.158 ± 13 km, respectively) and ran at velocities below *v*LT unlike the male runners who ran 6.3 ± 5.6% of their total training at *v*LT (5). However, the female runners compensated for their lower training distance by running longer distances at an intermediate velocity. This velocity is between the velocity at lactate threshold (*v*LT) and $v\dot{V}O_{2max}$ (10.3 ± 3.2 km for females vs. 7.8 ± 3.8 km for males) for distances between 1000 to 2000m. They also ran almost the same interval training distances as the male runners at or above $v\dot{V}O_{2max}$ (4.8 ± 5.5 km for females vs. 6.8 ± 3.8 km for males) for distances of 200 to 600m.

The idea that gender differences in running may disappear when the distance is increased beyond a marathon was hypothesized (9). The main reason is because females have a higher percentage of fat which is the main fuel for ultra-distances; also they have a smaller body size, thereby requiring less energy. However, a comparison between distances of 100-m to 200-km showed different results. The only distances at which males and females differed less than 10% were 100m (7.2%) and a marathon run (9.3%). For all other distances, the differences were more than 10%, where the highest gap was shown for 5-km run (14.3%). In distances greater than a marathon, males performed better than females in 50-km (15.2%), 50-miles (17%), 100-miles (14%), and 200-miles (14%).

Effect of Menstrual Cycle on Performance

The normal menstrual cycle is varied in length of 22 to 36 days for women ages 20 to 40, and is divided into three phases: the follicular phase, the ovulatian phase, and the luteal phase (8). From rest to exercise the factors that may influence performance the most are the fluctuating levels of the steroid hormones, estrogen and progesterone (8).

VT was tested during an incremental test to fatigue on a cycle ergometer in untrained women during both follicular and luteal phases (17). No significant differences between the luteal and follicular phases were found when VT was assessed by the respiratory equivalents for $\dot{V}O_2$ and VCO_2. However, the result of the VT when assessed by the V-slope ($\dot{V}_E / \dot{V}CO_2$), showed that in the luteal phase the VT was significantly greater than in the follicular phase (26.16 vs. 23.8 L/min respectively). However, only the slope, not the intercept was increased. Further, $\dot{V}_E$ was unchanged because the lower $\dot{V}CO_2$ at a given $\dot{V}O_2$ balanced the greater in $\dot{V}_E / \dot{V}CO_2$.

Different results during performance were shown in moderately-trained female runners (trained 4-8 miles per day, at least 3 d/wk) who performed a 30 min continuous run on a treadmill to examine the effect of the different phases of the menstrual cycle at 55% and 80% of $\dot{V}O_{2max}$ (46). Ventilation was significantly higher in the mid-luteal phase than in the early follicular phase in three conditions (rest: 12.4 ± 0.7 vs.10.3 ± .8 $l \cdot min^{-1}$; 55% $\dot{V}O_{2max}$: 46.2 ± .9 vs. 42.2 ± 1.4 $l \cdot min^{-1}$; 80%: 68.8 ± 3.0 vs. 63.3 ± 2.0 $l \cdot min^{-1}$, respectively). The main finding of the study was that running economy at 55% of $\dot{V}O_{2max}$ was not significantly different between phases. In contrast, at 80% of $\dot{V}O_{2max}$, VO_2 uptake at the luteal phase was significantly higher (less running economy) than in the follicular phase (41.4 ± .8 vs. 40.2 ± 0.5 $ml \cdot kg^{-1} \cdot min^{-1}$). The authors suggested that the runners' training status may affect the results and may not be applicable to elite female runners who are more familiar with running at fast paces.

Among elite female runners, the menstrual cycle appears to have insignificant effect on aerobic performance (16, 30). For instance, although $\dot{V}O_{2max}$ was slightly lower in the luteal phase than in the follicular phase (52.8 ± .8 vs. 53.7 ± .9 $ml \cdot kg^{-1} \cdot min^{-1}$,respectively) in trained athletes, the differences were insignificant (16). Further, $\dot{V}O_2$, $\dot{V}_E$, HR, RER, and RTF at $\dot{V}O_{2max}$ were not affected by menstrual status (amenorrheic vs. eumenorrheic) in female runners (30).

Summary

Most research that examined possible parameters for prediction of endurance performance have tested male athletes. Little research concerning running performance has generally included only highly trained female athletes and usually compared them to male athletes. When less trained females were examined it was usually to examine the effect of the menstrual cycle on their performance. RTF was not correlated to $\dot{V}O_{2max}$, but was shown to be relates to the velocity at $\dot{V}O_{2max}$ and LT. Therefore, the present study examined the correlation between 5-km run time and RTF at VT among heterogeneous group of 5-km female runners.

Chapter 3

Methods

The purpose of the study was to determine whether RTF at VT can predict 5-km run performance among heterogeneous group of female runners and to determine whether RTF was associated with $\dot{V}O_{2\,max}$. It was expected that RTF at VT will significantly predict 5-km run times among female runners. It was expected that $\dot{V}O_{2\,max}$ and RTF at VT will be significantly correlated to one another.

Participants

The study was approved by the Institutional Review Board at Barry University. Each participant read and signed a written informed consent (Appendix B) prior to participation, and a medical history form (Appendix C) was completed to confirm the absence of any medical conditions that would contraindicate or hinder participation in the study. In addition, the participants reported on their training for the last 12 months, including the best time for 5-km during the 12 months prior to the study (Appendix C).

Seventeen female runners from South Florida volunteered to take part in the study. They were recruited to participate in the study by flyers that were distributed at 5 and 10-km races in the area. The participants were screened based on their training history, and were included in the study if they had running experience of at least one year, had trained regularly in the 12 months prior the study, had trained at least 3 times per week, had participated in a 5-km race before the study, had trained for a specific 5-km race, had a personal best 5-km time that was less than 30 min and that was set within a year prior the study.

Procedure

The participants visited the Human Performance Laboratory at Barry University on two separate days. They were instructed to refrain from training a day before each test and to consume the last meal no less than two hours before the tests. They reported on their training history, and their menstrual cycle status and phase. Body mass was measured in pounds (± .2 kg) using a Health-O-Meter weight scale and height was measured in centimeters (± .1 cm) using a wall-mounted standmeter scale.

Two treadmill running tests were performed on separate days, one to measure $\dot{V}O_{2max}$ and VT and the other to determine RTF at *v*VT.

Maximal Oxygen Uptake ($\dot{V}O_2$ max)

An incremental test to exhaustion on a treadmill was performed. Five min of warm-up on the treadmill and 5 to 10 min of rest were given before the beginning of the test. The initial speed corresponded to the warm-up speed, and was rating on the Perceived Exertion (RPE) Borg Scale at 6-7 (6 - 20 scale) (7). The speed was increased by 0.4 mph (miles per hour) every one minute for 10 stages after which only the treadmill grade was increased by 2% every one minute. The participants were encouraged to run until exhaustion.

$\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}_E$ were measured continuously using the Parvo Medics' TrueOne® 2400 metabolic system. O_2 and CO_2 percentages and volume were continuously measured from expired gas collection. The system was calibrated before each test with a known percentage of O_2 and CO_2 and gas volume. RPE was measured using the Borg scale. Heart rate (HR) was monitored continuously using telemetry (Polar™).

$\dot{V}O_{2max}$ value was calculated as the average of the highest last three measures. In addition, it was necessary for one of the following criteria to be met: respiratory exchange ratio ≥ 1.15 or HR over 90% of the age-predicted maximal HR.

Ventilatory threshold (VT)

VT was assessed by graphing the results measured during the $\dot{V}O_{2max}$ test for the ventilatory equivalent of oxygen ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$). The point was determined where $\dot{V}_E/\dot{V}O_2$ exhibited a systematic increase without an accompanying rise in the ventilatory equivalent for CO_2 ($\dot{V}_E/\dot{V}CO_2$) (15). Two different observers determined the VT independently of each other. When disagreement occurred, a third observer, who was approved by both of the observers, verified the VT using the same method. The corresponding velocity (*v*VT) was determined based on the treadmill speed (15, 43). Figure 1 depicts example of the ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) the CO_2 ($\dot{V}_E/\dot{V}CO_2$) and the point at which VT occurs (arrow).

Run Time to Fatigue (RTF) at *v*VT

For the RTF test, runners were instructed to run until voluntary fatigue. After a 5-min warm-up and a short time to rest, the speed was increased in less than 15 sec to the *v*VT. Participants continued running at *v*VT until fatigue. During the first 5 min of the run, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$ and HR were continuously measured as described above. Following the initial 5 min HR and RPE was measured every 5 min.

Blood lactate was measured by a portable lactate *Accusport* analyzer from blood taken by finger stick at rest and immediately upon stopping the exercise. Participants were not provided encouragement by the investigator and were notified about the running speed only before the warm-up. The participants were allowed to wear a music set during the run.

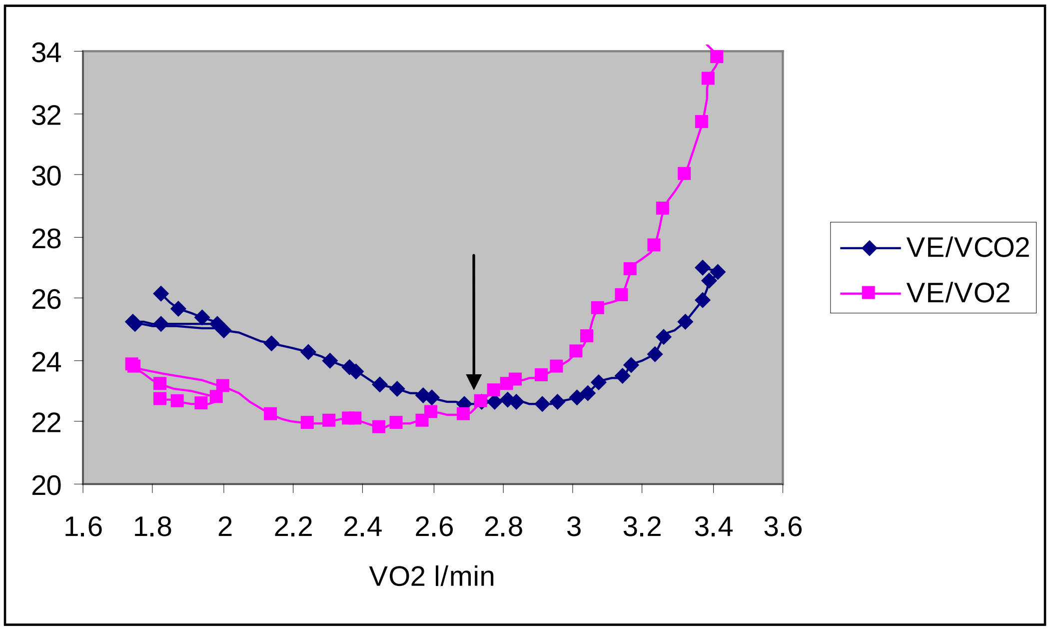

Figure 1. The Relationship Between $\dot{V}O_2$ and the Ventilatory Equivalent for O_2 ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$).

Statistical Analysis

A simple linear regression was calculated predicting 5-km run time from RTF at *v*VT. Additional simple linear regression was calculated for the relationship between RTF at VT and $\dot{V}O_{2max.}$ All data were presented as mean ± SD. Significance was set at $p \leq .05$.

Chapter Four

Results

The purpose of the study was to determine whether RTF at VT can predict 5-km run performance among heterogeneous group of female runners and to determine whether RTF was associated with $\dot{V}O_{2\,max}$. It was expected that RTF at VT will significantly predict 5-km run times among female runners and that $\dot{V}O_{2\,max}$ and RTF at VT will be significantly correlated to one another.

Descriptive Data

Of the 21 runners who began the study, four (19%) did not complete the study and their data were removed from the analyses. Two participants did not complete the RTF test because of scheduling conflicts, one participant finished the RTF prematurely because of fatigue from a competition the day before and one participant demonstrated $\dot{V}O_{2max}$ and 5-km personal best data that were outliers (>2 SD from the mean).

Although attempts were made to schedule all the RTF tests within one week of the $\dot{V}O_{2max}$ test, due to scheduling conflicts the RTF test was performed 2-4 weeks month after the $\dot{V}O_{2max}$ test for eight participants. Blood lactate and heart rate were not measured in one individual during the RTF test due to technical problems. Heart rate was measured immediately following the test by palpating the wrist and was recorded as maximal heart rate.

The initial purpose of the study was to predict 10-km run time from RTF. However, 10-km race are infrequent in South Florida compared to 5-km races. For this reason, some runners did not have a 10-km run time performance. They reported a personal best 5-km time run and also had trained for a prospective 5-km race. Therefore, one of the hypotheses was modified accordingly by predicting 5-km run time from RTF at VT. This hypothesis is based on the fact that 5-km races are considered to be long distance events. Descriptive data including personal best 5-km time are presented in Table 1.

$\dot{V}O_2$ max Test

$\dot{V}O_{2max}$ test data, including maximal and VT, are presented in Table 2. At the end of the test, all the participants achieved HR value that was higher than 90% of the age predicted maximal HR. Thirteen runners achieved RER ≥ 1.15. The test was terminated because of voluntary fatigue.

The incremental test to exhaustion on a treadmill was performed according to the following protocol: the initial speed was estimated by the participant as RPE of 6-7 on the Borg scale and was increased by 0.4 mph every one minute for 10 stages after which only the treadmill grade was increased by 2% every one minute. The participants were encouraged to run until exhaustion. Maximal speed and grade were 8.95 ± .45 mph and 2.35 ± 1.68 %, respectively. Mean number of running stages was 11.24 ± .903 and ranging from 10-13.

RTF Test

RTF data are presented in Table 3. Mean running speed was 7.58 ± .44 mph with a range of 6.8 to 8.4 mph. Mean RTF was 39.2 ± 15.8 min with a range of 15.0 to 61.0

min. Heart rate, RPE and blood lactate were measured during the first 5 minutes and again immediately following the test.

Performance Predictors

A simple linear regression was calculated to predict 5-km run time from RTF. RTF did not predict 5-km run performance ($F_{(1, 15)} = 1.147$, $p > .05$) with an $R^2 = .071$. This relationship is presented in figure 2.

A Pearson correlation coefficient was calculated for the relationship between $\dot{V}O_{2max}$ and RTF. There was no significant correlation between $\dot{V}O_{2max}$ and RTF ($r (15) = .075$, $p > .05$). The relationship between $\dot{V}O_{2max}$ and RTF at VT are presented in figure 3.

Unexpectedly, $\dot{V}O_{2max}$ significantly predicted 5-km run performance ($F_{(1, 15)} = 19.363$, $p < .001$) with an $R^2 =.563$. The relationship is presented in figure 4. Furthermore, a strong positive correlation was found by calculating a Pearson correlation coefficient for the relationship between $\dot{V}O_{2max}$ and years of experience ($r (15) = .535$, $p < .05$). The relationship is presented in figure 5. Additional Pearson correlation coefficient calculation found a strong correlation coefficient for the relationship between $\dot{V}O_{2max}$ and $\dot{V}O_2$ at VT ($r (15) = .804$, $p < .05$). The relationship is presented in figure 6. This relationship led to additional significant correlation coefficient between $\dot{V}O_{2max}$ and running speed during the RTF test ($r (15) = .659$, $p < .05$). The relationship is presented in figure 7.

A significant regression equation was found between 5-km run performance and running speed during the RTF test ($F_{(1, 15)} = 5.658$, $p < .05$) with an $R^2 =.274$. This relationship is presented in figure 8.

Table 1. Descriptive Data.

	Mean	SD	Range
Age (yr)	32	8.75	19 – 45
Height (cm)	167.4	5.1	157.0 – 178.0
Weight (kg)	60.9	5.9	51.4 – 73.6
Experience (yr)	5.2	3.2	1.0 – 10.0
5-km personal best (min)	24.0	2.4	20.0 – 28.0

Table 2. $\dot{V}O_2$ max Test Results.

	Mean	SD	Range
$\dot{V}O_{2max}$ (ml· min^{-1}· kg^{-1})	48.1	3.3	44.0 – 54.0
$\dot{V}_E$ max (l· min^{-1})	98.0	11.6	79.3 – 126.6
RERmax	1.16	.04	1.06 -1.28
HRmax (bpm)	184	9	166 - 199
$\dot{V}O_2$ at VT (ml· min^{-1}· kg^{-1})	37.1	2.5	32.4 – 42.0
% $\dot{V}O_{2max}$ at VT	77.1	3.4	70.6 – 85.4
HR at VT (bpm)	161	9	149 - 168
RPE at VT	13	2	8 - 16

Table 3. RTF Test Results.*

	Mean	SD	Range
$\dot{V}O_2$ (ml· min^{-1}· kg^{-1})	38.9	3.0	34.9 – 45.5
% $\dot{V}O_{2max}$	81.3	4.4	75.1 – 90.3
$\dot{V}_E$ (l· min^{-1})	67.8	9.2	56.9 – 92.5
HR beg (bpm)	169	9	153 – 185
HR end (bpm)	184	11	164 - 203
Lactate beg (mMol)	2.3	.7	1.0 – 3.4
Lactate end (mMol)	7.5	3.6	3.1 – 16.6
RPE beg	11.5	1.2	9 - 13
RPE end	18.5	.8	17 - 20

* Heart rate, lactate and RPE were recorded at the beginning (beg) and end of the test.

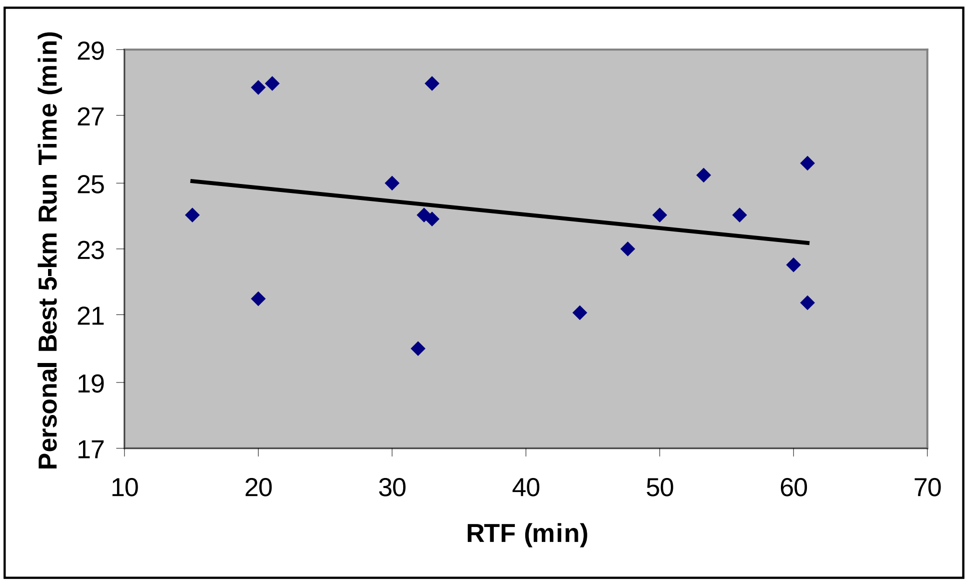

Figure 2. The Relationship Between RTF and 5-km Run Time

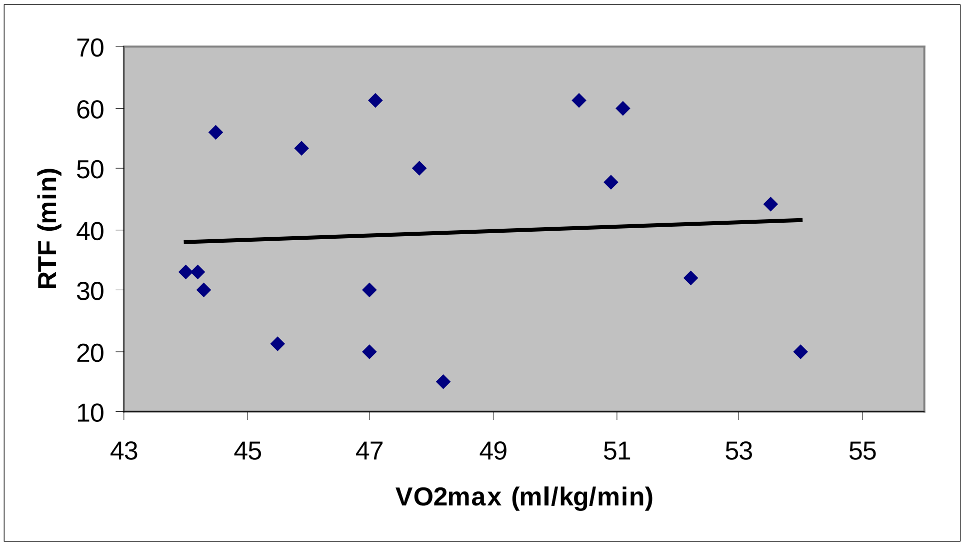

Figure 3. The Relationship Between $\dot{V}O_2$ max and RTF.

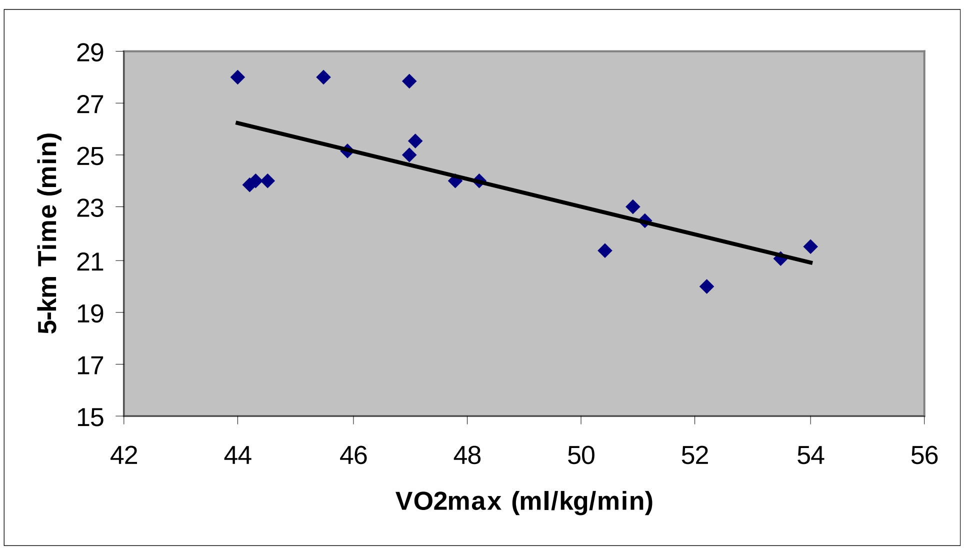

Figure 4. The Relationship Between 5-km Run Time and $\dot{V}O_2$ max.

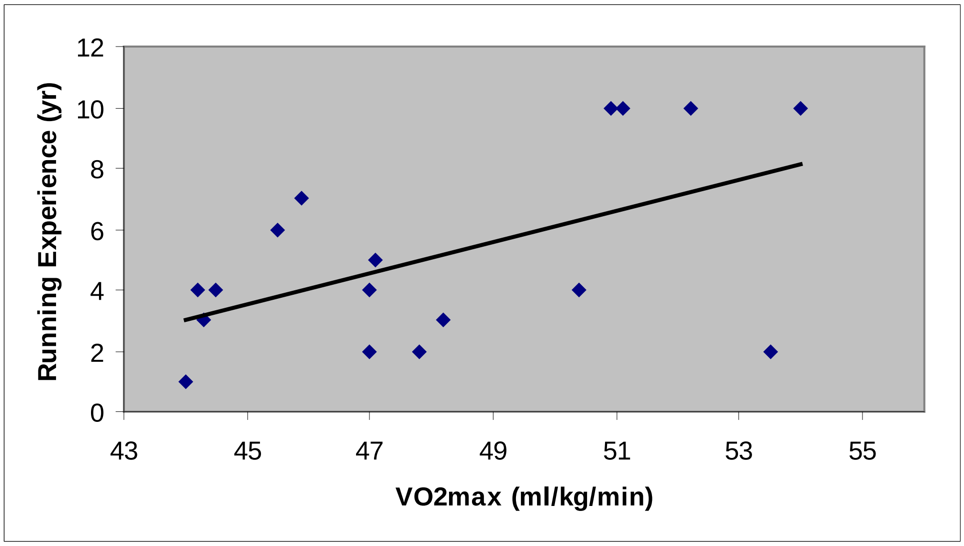

Figure 5. The Relationship Between Years of Experience and $\dot{V}O_2$ max.

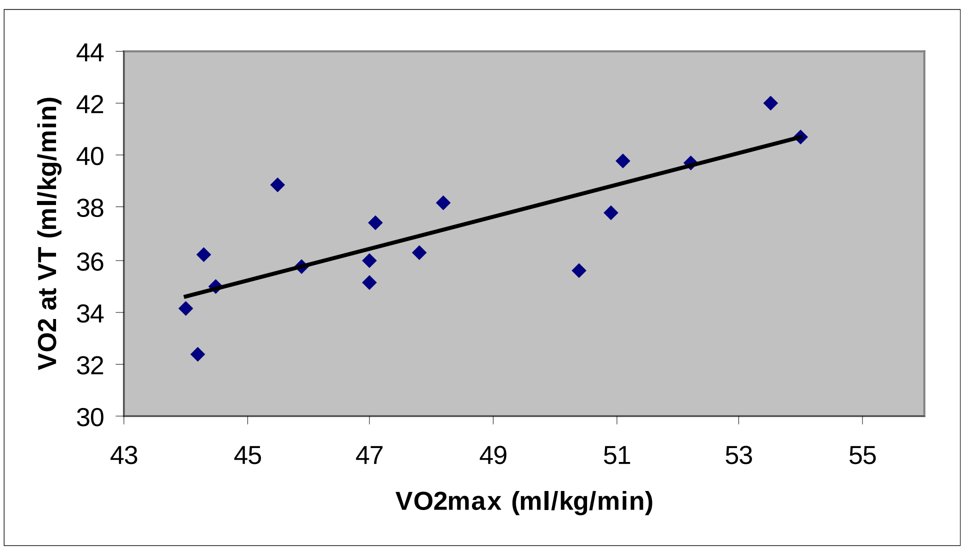

Figure 6. The Relationship Retween VT and $\dot{V}O_2$ max.

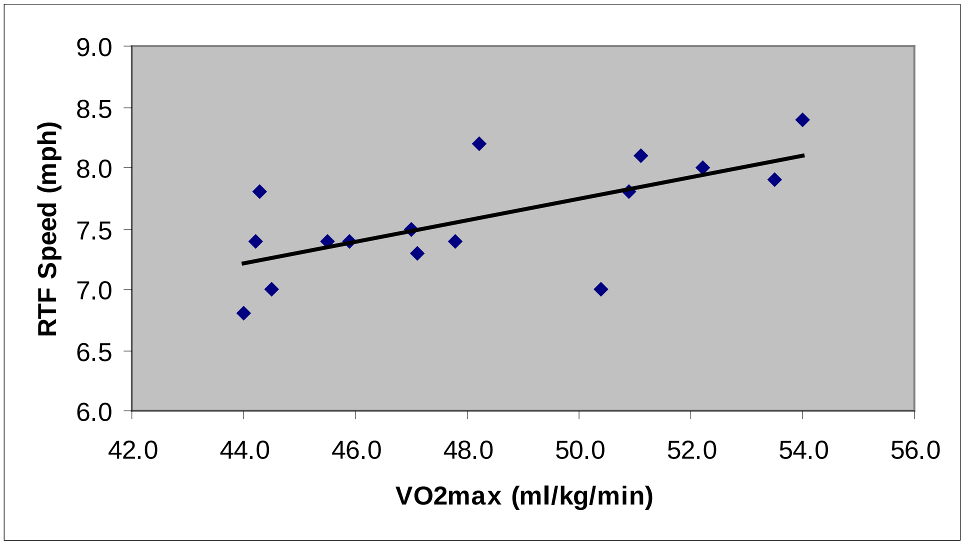

Figure 7. The Relationship Between $\dot{V}O_2$ max and RTF Speed.

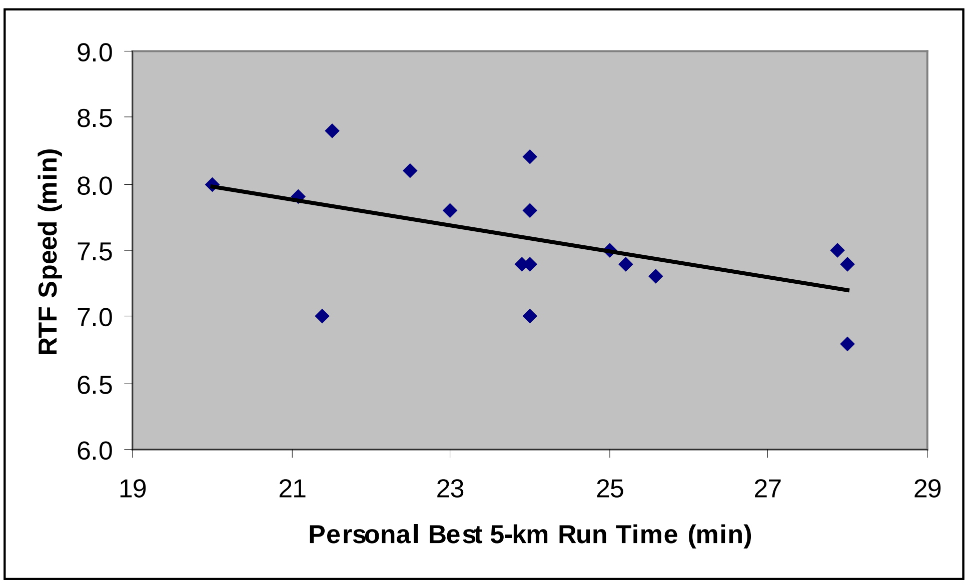

Figure 8. The Relationship Between RTF Speed and 5-km Run Time.

`Chapter Five

Discussion

The purpose of the study was to predict 5-km run performance from RTF at VT among heterogeneous group of female runners. The hypotheses were that RTF at VT will predict 5-km run time and that $\dot{V}O_{2max}$ and RTF will be correlated to one another.

While most studies sought to predict running performance among heterogeneous groups of male athletes, examine gender differences or test homogeneous groups of males, this study examined running performance among a heterogeneous group of recreational long distance female runners. This group may represent the majority of long distance female runners in South Florida who participate in road races but do not train according to a designed program or with coaching assistance.

Running time to fatigue has been used to predict distance running performance at velocities such as $v\dot{V}O_{2max}$ and velocities associated with blood lactate levels of 2mM and 4mM (2, 6, 10, 36, 46). At these velocities RTF was correlated to running performance in distances from 3 to 21.1-km in homogeneous groups of runners. We examined the run time to fatigue among runners who sustained submaximal steady state $\dot{V}O_2$ corresponding to VT

Run Time to Fatigue as a Performance Predictor

The essential result of the study was that RTF at VT did not predict 5-km run time among a heterogeneous group of long distance female runners. The reason may be related to differences in performance during road race and on a treadmill. Farrell and colleagues showed that experienced marathon runners demonstrated a marathon race pace that was 3 to 7 m/min faster than the speed associated with the level of onset of blood lactate accumulation (OBLA) (20). The authors suggested that the treadmill data may underestimate the energy cost associated with the road race conditions. The participants may run at a higher fractional of their $\dot{V}O_{2max}$ during a race than that was measured from treadmill data because of varying conditions, such as training, environmental factors, and experience. In addition, events such as road races that include other runners and spectator may increase the runners' motivation to run faster compared to run by themselves on a treadmill in lab conditions.

Another reason for the fact the RTF at VT did not predict 5-km run may be that 5-km requires a higher percentage of anaerobic capacity than the *v*VT. Although, 5-km run is considered a long distance, it is performed at a higher percentage of anaerobic capacity compared to other longer distances such as 10-km or marathon (21, 34). During 5-km run, approximately12.5% of the ATP is provided by anaerobic glycolysis and 87.5% by aerobic processes. For 10-km and a marathon run, the anaerobic glycolysis pathway provides about 3% and 0% of the ATP, respectively and the aerobic pathway provides 97% and 100% of the ATP, respectively (34). Therefore, fatigue in 5-km may be because of accumulation of lactic acid. This was demonstrated in the present study, when blood lactate level was significantly increased from resting level to the end of the RTF (Mean: 2.3 ± .2 to 7.5 ± .9 mM). However, the participants in the present study trained to participate in road races of duration ranged from 5-km to a marathon. Their training method consisted mostly of long distance runs at low to moderate intensities. For this reason they demonstrated different abilities to maintain the speed at the RTF test. For instance, the participant who reported the fastest 5-km personal best time (20 min), trained during the course of the data collection for the Hawaiian Iron-Man triathlon. She reduced the amount of high intensity interval training and increased the weekly mileage at low intensities. This may be the reason for her difficulties to sustain the RTF at VT longer than 32 min, which was below the group average of 39.23 ± 15.86 min.

Interestingly, nine participants were able to sustain the *v*VT for a longer time than the 5-km personal best run time. Surprisingly, the *v*VT of these runners was similar to or faster than their 5-km personal best. This may be because the participants in this study probably underestimated their running abilities. Most of them participated in road races in a purpose of completing the distance, performing better than other women or running faster than other women at their age group. Most of them did not challenge themselves to run faster in order to improve their personal best times. However, in the RTF test, the pace was set and the runners were acknowledged that they were not expected to reach a certain time or duration. These facts probably reduced their anxiety from the test and may increase their motivation to accumulate running time.

Their ability to run faster and longer than their 5-km personal best may be also related to inherited physiological factors, such as type of muscle fibers, amount of aerobic and anaerobic enzymes and the ability to sustain increase in lactic acid in the muscles (10, 46). The importance inherited physiological abilities was shown in black and Caucasian long runners with similar $\dot{V}O_{2max}$ values (61.9 ± 5.9 vs. 65.2 ± 7.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively), who were examined in their ability to run until fatigue at 72, 80, 88, and 92% of each individual peak treadmill velocity that was measured during a $\dot{V}O_{2max}$ test (46). The black runners had significantly better results in the following measurements compared to the Caucasian runners: 21% longer time to fatigue, blood lactate accumulation that was lower in 38% and 50% higher level of oxidative enzymes, but no correlation was found between $\dot{V}O_{2max}$ and RTF. Although, the participants in the present study demonstrated heterogeneous values of $\dot{V}O_{2max,}$ no significant relationship was found between RTF and $\dot{V}O_{2max}$ as well.

The reason that RTF and $\dot{V}O_{2max}$ were not correlated to one another in the present study may be attributed to the fact that the runners trained for a large range of distances from 5-km to a marathon and their trainings were performed at low to moderate intensities. Their $\dot{V}O_{2max}$ value was increased as a result of these training. However, success in RTF may be related to specific training for a certain distance in order to gain fatigue resistance against specific fatigue mechanism (1, 2, 3, 4, 5, 10, 22, 38, 46). For instance, the participant who demonstrated the highest $\dot{V}O_{2max}$ (54.0 $ml \cdot kg^{-1} \cdot min^{-1}$), trained during the course of the data collection for the Chicago Marathon and therefore, reduced the amount of high intensity interval training and increased her weekly mileage at low intensities (< 70% $\dot{V}O_{2max}$). For this reason, she ran the RTF at VT in 20 min which was less than the group average. The effect of different training methods was also shown when middle distance runners who had similar $\dot{V}O_{2max}$ as long distance runners (72.7 ± 5.6 vs. 73.4 ± 4.6 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) were tested (2). The middle distance runners were able to run longer at $v\dot{V}O_{2max}$ than the long distance runners (16.2 ± 3.8 vs. 14.0 ± 2.1 min, respectively) because they trained at velocities that were closer to their $\dot{V}O_{2max}$ compared to the long distance runners who trained at lower intensities (2).

$\dot{V}O_2$ max as a Predictor of 5-km

$\dot{V}O_{2max}$ significantly predicted 5-km run performance and a significant correlation was shown between *v*VT and 5-km run time. The group of athletes demonstrated a wide range of 5-km times and $\dot{V}O_{2max}$ values. There was a 16% difference in $\dot{V}O_{2max}$ between the higher and lower values and 15% difference between the fastest and the slowest times. Traditionally, $\dot{V}O_{2max}$ has been considered an important determinant for success in long distance events in heterogeneous runners (4,14, 21, 23). In addition, $\dot{V}O_{2max}$ increases as a result of both long duration training at a moderate pace and interval training (24, 42). Our data are similar to a previous study that showed that $\dot{V}O_{2max}$ was highly correlated with 5-km, 10-km, and 16.09 running pace (r = .91, r = .92, r = .88, respectively). The runners in that study were moderately to highly-trained female runners who had comparable characteristics to the present study such as moderate variability of $\dot{V}O_{2max}$ (59.7 ± 5.3 $ml \cdot kg^{-1} \cdot min^{-1}$), and at least one year of running experiences (21).

Speed of running at $\dot{V}O_{2max}$ or lactate threshold has been correlated with performance (4, 6, 10, 39, 46). In the present study, *v*VT was correlated to 5-km run time. However, the results are not surprising because with the increase in $\dot{V}O_{2max,}$ there was an increase in the absolute value of $\dot{V}O_2$ at VT and therefore a faster *v*VT. Poole and Geasser showed that $\dot{V}O_{2max}$ and VT increased in three groups of runners who trained for 8 weeks 3 d/wk at low intensity exercise (55 min at 50% $\dot{V}O_{2max}$), moderate exercise intensity (35 min at 70% $\dot{V}O_{2max}$), or high intensity exercise (10 bouts of 2 min at 105% $\dot{V}O_{2max}$) (24). However, $\dot{V}O_{2max}$ increased significantly in all group with no differences between groups, whereas, the greatest increase in VT was in the group who trained at high intensity.

In the present study, the relationship between $\dot{V}O_{2max}$ and running performance may very well be related to years of experience. Three of the four runners who demonstrated the highest $\dot{V}O_{2max}$, had 10 years of experience. This is likely so participants who had more years of experience train to improve their running ability by raising the duration of the runs and incorporating high intensity intervals runs in their training compared to the runners who had less years of experience and ran at low to moderate intensities. Furthermore, the experienced runners raised the challenge with the years by racing in longer distances or running faster at the same distances in order to improve personal best run times. In contrast, the less experienced runners reported that their main goal is to finish the race and not to improve their running times. Therefore, they trained and raced at low to moderate exercise intensities which may result in lower $\dot{V}O_{2max}$, $\dot{V}O_2$ at VT, and *v*VT than the experienced runner.

Practical Application

$\dot{V}O_{2max}$ is a good predictor in heterogeneous groups of runners. Although, the value of $\dot{V}O_{2max}$ depends mostly on heredity, it increases with the progression of training (duration and intensity) and can be increased by 5-15% (41). For this reason, recreational female runners should increase duration and intensity of training in order to reach a higher potential of their $\dot{V}O_{2max}$. However, in order to improve fatigue resistance, recreational female runners should train at velocities similar to the speed they intend to run during road races.

The importance of training methods to improve fatigue resistance at a specific distance is shown in highly trained homogeneous group of runners who are already close to their highest potential of $\dot{V}O_{2max}$. In this group, the most successful athletes are those who can sustain a given velocity and high percentage of $\dot{V}O_{2max}$ during racing at any distance because they have superior fatigue resistance. Therefore, athletes should include training at a velocity similar to the pace they intend to run during races. This will increase their fatigue resistance against a specific fatigue mechanism. They also should be challenged to run faster during road races in a purpose of improving personal best

Conclusion

RTF at VT does not predict 5-km time among a heterogeneous group of recreational long distance female runners. This is mainly for the reason that the participants were not considered 5-km specialists. They trained for long duration at a low to moderate intensity which increases resistance to fatigue mechanism that associated with reduction in blood glucose level. However, 5-km run consist of high percentage of anaerobic capacity that results in other fatigue mechanism such as increase in lactic acid in the muscles. In addition, treadmill run may underestimate the energy cost associated with road race conditions.

As was established in previous studies, this study showed that $\dot{V}O_{2max}$ is the best predictor for success in endurance events in a heterogeneous group of runners. $\dot{V}O_{2max}$ was correlated to VT, *v*VT, 5-km run performance and years of experience but was not correlated to RTF at VT. The reason for these results may be attributed to the fact that $\dot{V}O_{2max}$ increases with training in both low to moderate and high training intensities.

However, in order to improve ability to sustain run until fatigue at a given speed, a runner should train at a similar speed.

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Appendix A

Research with Human participants Protocol Review

Barry University

Research with Human Subjects
Protocol Form

PROJECT INFORMATION

1. **Title of Project**

   Does Running Time to Fatigue at Ventilatory Threshold and VO_2max Predict 10-Km Run Performance in Female Runners?

2. **Principle Investigators**

   Tsuri Castel, BEd CSCS
   Graduate Student
   HPLS - Department of Sport and Exercise Science
   786-554-8407
   castelt@bucmail.barry.edu

3. **Faculty Sponsor** (If Applicable)

   Constance Mier , PhD CSCS
   Associate Professor, Coordinator of Exercise Science
   HPLS - Department of Sport and Exercise Sciences
   (305) 899-3573
   cmier@mail.barry.edu

4. **Funding Agency or Research Sponsor**

   NA

5. **Proposed Project Dates**
   Start______9/05_________
   End_______12/05_________

A. Project activity STATUS is: (Check one of the following three as appropriate.)

__X___**NEW PROJECT**
______**PERIODIC REVIEW ON CONTINUING PROJECT**
______**PROCEDURAL REVISION TO PREVIOUSLY APPROVED PROJECT** (Please indicate in the **PROTOCOL** section the way in which the project has been revised.)

B. This project involves the use of an **INVESTIGATIONAL NEW DRUG (IND) OR AN APPROVED DRUG FOR AN UNAPPROVED USE** in or on human subjects.

______Yes ___X___ No

C. This project involves the use of an **INVESTIGATIONAL MEDICAL DEVICE (IMD)** or an **APPROVED MEDICAL DEVICE FOR AN UNAPPROVED USE.**

______Yes ___X___ No

D. This project involves the use of **RADIATION** or **RADIOISOTOPES** in or on human subjects.

______ Yes ___X___ No

E. This project involves the use of Barry University students as subjects. (If any students are minors, please indicate as well.)

__X____ Yes ______ No
______ Minors

F. **HUMAN SUBJECTS** from the following population(s) would be involved in this study:

0_____Minors (under age 18)
0_____Fetuses
0_____Abortuses
0_____Pregnant Women
0_____Prison
0_____Mentally Retarded
0_____Mentally Disabled
0_____Other institutionalized persons (specify)
____
___X___Other (specify)
Female Runners from South-Florida Area

G. Total Number of Subjects to be studied:____30_____

Description of Project

1. **Abstract**

Prediction of endurance performance will be investigated using physiological adaptations, such as $\dot{V}O_{2max}$, running economy, lactate threshold (LT), and running time to fatigue (RTF) at maximal and submaximal velocities. The ventilatory threshold (VT) was less studied because it was used to be related to the LT. However, research showed that the VT may occur at a different intensity during exercise and is improved following different type of training compared to the LT. The VT refers to a non-linear increase in minute ventilation of oxygen (O_2), and is determined by a non-invasive method by graphing the ratios of the minute ventilation of O_2 and carbon dioxide (CO_2) from the results of the $\dot{V}O_{2max}$ test on a treadmill. Most studies that sought to investigate the physiological variable relating to endurance running included only male runners. When female runners were examined, it was usually to compare their performance to males when some of the variables were controlled. Further, when only female athletes are studied, they have been mostly elite athletes. In contrast, research on less-trained females is scant and usually examined the effect of the menstrual cycle on performance. Therefore, the purpose of the study is to predict 5-km run time from RTF at *v*VT heterogeneous group of female runners.

2. **Recruitment Procedures**

Volunteers will be 30 female runners from South Florida. They will be recruited to participate in the study by flyers that will be distributed at 5 and 10-km races in the area. The participants were screened based on their training history, and will be included in the study if they had running experience of at least one year, had trained regularly in the 12 months prior the study, had trained at least 3 times per week, had participated in a 5-km race before the study, had trained for a specific 5-km race, had a personal best 5-km time that is less than 60 min and was set within a year prior the study.

3. **Methods**

Each individual will visit the Human performance Laboratory in the Department of Sport and Exercise Sciences on two occasions. They will be instructed to refrain from training a day before each test and to consume the last meal no less than two hours before the tests. They will report on their training history and their menstrual cycle status and phase prior to the tests. During the first visit, the following will be performed:

1. Body weight and height measurements.
2. Exercise warm up. Each participant will be allowed to warm up on the treadmill at a light intensity for approximately 5 minutes.
3. VO_{2max} treadmill test. The test uses a graded treadmill protocol that begins at a light intensity. Every 1 minute, the intensity was increased by 0.4mph (miles per hour) for 10 minutes. Then, only the grade of the treadmill will be increased by 2%

until the participant stopped exercising because of fatigue. The fastest speed and the highest grade achieved during the test depend on the fitness level of the participant. During the test, continuous measurement of heart rate (the participants wear a heart rate monitor consisting of a chest strap) and oxygen uptake will be measured. For oxygen uptake measures the participant breaths room air through a two-way breathing valve that is connected to an expired gas hose. Expired gases are continuously collected and volume and percent of oxygen and carbon dioxide are measured. During the test the participants will be asked to estimate their perceived exertion on a scale of 6 to 20 every 1 minute. The test is a maximal test, meaning the participant will be asked to run to exhaustion. Typically, this test does not last longer than 15 minutes.

4. As soon as exhaustion has been achieved, the participant will actively cool-down at a light intensity for 5-10 minutes. Total time for this test includes screening, warm-up and cool-down is approximately 40 min.

During the second visit, the following will be performed:

5. The RTF at *v*VT test on a treadmill will be performed within a month following the $\dot{V}O_{2max}$ test. The runners will be instructed to run until voluntary fatigue. After a 5-min warm-up and a short time to rest, the speed will be increased in less than 15 sec to a speed corresponding to VT and the participants ran at this constant speed until voluntary fatigue. During the first 5 min of the run, oxygen uptake and heart-rate will be continuously measured. Then, the participants will be disconnected from the metabolic system while running, and only heart-rate will be monitored as described above, and RPE will be estimated every 5 min. Blood lactate will be measured only during the RTF at *v*VT test at rest and immediately upon stopping the exercise by a portable lactate analyzer from blood drawn by finger stick.
6. As soon as exhaustion has been achieved, the participant performed actively cool-down at a light intensity for 5-10 minutes. Total time required for this test will be more than 60 minutes including warm-up, cool-down and preparation.

4. **Alternative Procedures**

There are no alternatives to this study available to the participants. The participants are allowed to elect not to participate and are allowed to withdraw anytime without adverse effect.

5. **Benefits**

If the results of this study will demonstrate that 5-km run is related to performance at VT, well-designed training programs that include training to improve the VT may be developed. Further, female runners generally have not reaped the benefits of well-designed training programs because most of the studies examine males only.

Women are different from men in terms of physiological characteristics such as lower $\dot{V}O_{2max}$, higher fat percentage, and women metabolism is influenced by the menstrual cycle. Therefore, studies with female participants have to address methods that will consider these factors.

6. **Risks**

The risks involved with these tests are minimal and each participant runs regularly at high intensities as a normal part of training for competitive running races. The participant may experience temporary fatigue immediately following the tests, common for such exercise. To minimize fatigue, we will ask the participant to not engage in vigorous physical activity the day before or the day of each test. Because maximal physical effort is required for these tests, the risks of deaths are greater than for moderate levels of physical activity. However, the risk among athletes has been reported to be negligible. To minimize this risk, the participants will fill-out a health-status questionnaire. No participant had a known cardiorespiratory or metabolic condition considered to be a contraindication for exercise, have 2 or more risk factors for cardiovascular disease and a musculoskeletal injury that could hinder the ability to perform exercise. All tests will be supervised by Dr. Mier and Tsuri Castel, both highly experienced with these tests.

7. **Anonymity/Confidentiality**

To ensure confidentiality, all data will be numerically coded so that no names are associated and only the primary investigators and research assistants have access to the data. All data will be stored in a locked file cabinet in the Barry University Human Performance Laboratory, and will be destroyed in 5 years following the study. Consent forms will be kept separately in a locked cabinet, and will also be destroyed in 5 years following the study.

8. **Consent**

I certify that the protocol and method of obtaining informed consent as approved by the Institutional Review Board (IRB) was followed during the period covered by this research project. Any future changes will be submitted to IRB review and approval prior to implementation. I prepared a summary of the project results annually, to include identification or adverse effects occurring to human subjects in this study.

____________   ____________________________

Date   Principal Investigator

____________   ____________________________

Date   Principal Investigator

Appendix B

Informed Consent Form

Barry University
Dept. Of Sport and Exercise Science
Consent Form

You are invited to participate in a study conducted by Tsuri Castel a Graduate student at the Department of Sport and Exercise Science, at Barry University. The purpose of this study is to predict 10-km run performance from maximal aerobic capacity (VO_2max) and running time to fatigue (RTF) at ventilatory threshold. You will be among 30 female runners.

As part of your participation in this study, you will visit the Human Performance Laboratory on the campus of Barry University on 2 separate days for approximately 1 hour per visit. The first visit will include a test to measure your VO_2max. The second visit will include a test to measure RTF at ventilatory threshold. Both tests are described below:

1. VO_2max. This test requires you to run on a treadmill for approximately 10-15 minutes. This test begins at a slow pace followed by 1-min increments of increasing speed by 0.4mph (miles per hour) for 10 minutes (stages). If you reached the 10th stage and can continue to run, the incline is increased every 1 minute by 2% until you signal that you can no longer continue. During the test the amount of oxygen being consumed in the body is measured by having you breathe through a valve into a hose that sends expired air to an analyzer. You breathe normal room air during the entire test. Heart rate will be measured using a chest strap that is comfortably fitted around your chest. Every minute you will be asked to estimate your perceived exertion on a scale of 6 to 20. Total time required for this test is approximately 40 minutes, including warm-up, cool-down and preparation.
2. RTF at ventilatory threshold. This test will be performed approximately one week following the VO_2max test. After a 5-min warm-up and a short time to rest, the speed will be increased in less than 15 seconds to a speed corresponding to your ventilatory threshold (determined during the VO_2max test). You will run at the constant speed until voluntary fatigue. During the first 5 min of the run the oxygen uptake will be measured as described above. During the entire run, heart rate and perceived exertion will be measured as described above. Blood lactate will be measured before and at the end of the run, from blood drawn by finger stick. Total time required for this test may be more than 60 minutes, depending on you, including warm-up and preparation.

The risks involved with these tests are minimal. You will experience temporary fatigue and possibly mild muscle soreness following the VO_2max and RTF tests, common for these tests. To minimize any soreness that may result, we ask that you do not engage in vigorous physical activity the day before or the day of each test. Because maximal physical effort is required for these tests, the risks of deaths are greater than for moderate levels of physical activity. However, the risks are extremely low. To minimize this risk, prior the tests you will be asked to fill-out a health-status questionnaire to ensure that you are without a cardiopulmonary disease and free of any musculoskeletal condition that could impede physical activity. Your menstrual cycle may have an effect on your training and performance. Because of this, you will be asked to report information concerning your menstrual cycle (e.g., length, regularity, etc), and how it might affect you as an athlete. The tests will be supervised by Tsuri Castel and Dr. Constance Mier, both highly experienced with these tests and trained in CPR and emergency procedures.

The benefits to you for participating in this study are the knowledge of you fitness level, and may assist you to improve your training program.

Your participation is voluntary and you may elect not to participate at any time without prejudice or having any adverse effects on your status as a competitive runner. Any data collected from your participation will be kept confidential and will be destroyed in 5 years following the study. Only those directly involved with the tests will have access to this information, which will be kept in a locked cabinet. Signed consent forms will be kept separate from data information in a locked file.

Further information regarding the described procedures can be obtained by calling Dr. Mier at 305-899-3573 or Tsuri castel at 786-554-8407. If you have any questions specific to the IRB procedures, please call Nildy Polanco at (305) 899-3020.

CONSENT BY PARTICIPANT

My signature signifies that I have read the consent form and received a copy for my record. I understand the procedures for testing as they have been explained by the investigator and voluntarily agree to participate in the testing. I am aware of the risks which might be involved with my participation and understand that these tests are performed for informational, screening, and/or research purposes only and that the principal investigator makes no claims regarding medical diagnoses and/or treatment as a result of information gathered. I also understand that I may voluntarily withdraw from this study at any time with no adverse impact.

______________________________ ____________________

Signature of Participant Date

______________________________ ____________________

Signature of Investigator Date

Appendix C

Health History Questionnaire

Human Performance Laboratory
Department of Sport and Exercise Sciences
Barry University
HEALTH HISTORY QUESTIONNAIRE

Name ______________________________ Date ______ Phone (H) ____________

Date of Birth ___________________________ Phone (W) _______________

Home Address ____

____Zip _____________

Gender: F M

MEDICAL HISTORY

Physical Injuries

____

Other limitations (including pregnancy)

____

Have you ever had any of the following cardiovascular conditions? Please check.

Heart attack ________Heart surgery_______
Chest pain ________Swollen ankles_______
Irregular heart beats ________Heart murmur_______
Valve problems ________Dizziness _______
Shortness of breath ________Congestive heart failure_______
Heart catheterization ________Heart angioplasty_______
Pacemaker ________Congenital heart disease_______
Other _______________________________________

Has anyone in your immediate family had any of the above conditions? __________. If yes, please list the relation of the person, the condition and approximate age when diagnosis was made or when surgery was performed

____

Have you ever had any of the following? Please check.

Hepatitis/HIV ________ Cancer_______
Rheumatic fever ________ High blood pressure_______
Kidney/liver disease ________ Obesity_______
Diabetes ________ High cholesterol (> 200)_______
Asthma ________ Stroke_______
Emphysema ________ Depression______

Do you or have you ever smoked cigarettes? Y N If yes and if you no longer smoke, how long has it been since you last smoked?

____

Are you aware, through your own experience or a doctor's advice of any other physical reason that would prohibit you from exercising without medical supervision? Y N If yes, please explain.

____

____

Do you have a menstrual cycle? Y N

Are your menstrual cycles regular? Y N If yes, approximately how many days between periods?

If your menstrual cycles are not regular, describe them as best as you can

____

____

When was your last period? ____

Do you feel your training is affected by your menstrual cycles? Y N If yes, explain as best as you can.____

____

What is your prime sport (marathon, triathlon, 5-km run etc.)? ________________________________

How many years of experience do you have in road races? ___________________________________

Have you experienced any cessation from training (greater than 3 weeks) in the last 12 months? Y N

If yes, explain why.

____

____

____

Have you ever participated in a 5-km race? Y N If yes, when was the last race?________________

What is your personal best in 5-km run? When did you set the time?

____

How many miles do you run during a week? ______________________________________

____

Do you include interval runs in your training program? Y N If yes how many days per week do you run intervals training?

____

Appendix D

Raw Data

Descriptive

Participants	Age (yrs)	Body Mass (kg)	Height (cm)	Experience (yrs)	5-km PB (min)
1	25	59.1	168	2	21.08
2	26	68.2	178	10	22.50
3	37	54.5	165	10	21.50
4	26	53.6	165	10	23.00
5	35	59.1	165	5	25.58
6	21	51.4	157	4	25.00
7	36	62.7	168	6	28.00
8	39	65.5	170	10	20.00
9	43	54.5	168	4	21.38
10	45	55.5	165	4	23.91
11	41	65.9	170	1	28.00
12	24	73.6	171	2	27.86
13	45	61.4	163	4	24.00
14	41	62.7	163	7	25.21
15	19	63.2	175	3	24.00
16	30	59.1	163	3	24.00
17	22	65.9	173	2	24.00

$\dot{V}O_2$ max Test

Participants	$\dot{V}O_{2max}$ (ml· min^{-1}· kg^{-1})	RER max	$\dot{V}_E$ max (l· min^{-1})	$\dot{V}O_{2max}$ at VT (ml· min^{-1}· kg^{-1})	% $\dot{V}O_{2max}$	HR at VT (bpm)	Maximal speed (mph)	Grade (%)
1	53.5	1.15	106.06	78.50	42.00	157	9.5	2
2	51.1	1.13	110.43	77.88	39.80	156	8.5	6
3	54.0	1.17	85.30	75.37	40.70	167	9.6	2
4	50.9	1.17	94.33	74.26	37.80	172	9.0	4
5	47.1	1.17	98.51	79.40	37.40	163	8.5	4
6	47.0	1.15	87.83	74.68	35.10		8.7	4
7	45.5	1.16	98.71	85.49	38.90	157	9.0	0
8	52.2	1.13	126.62	76.00	39.70	155	10.0	0
9	50.4	1.11	93.29	70.60	35.60	155	9.0	2
10	44.2	1.18	95.59	73.30	32.40	178	9.0	2
11	44.0	1.16	94.54	77.50	34.10	156	8.5	0
12	47.0	1.28	115.89	75.59	36.00	166	8.5	4
13	44.5	1.19	88.65	78.65	35.00	149	8.5	2
14	45.9	1.23	95.01	77.77	35.70	150	8.5	2
15	44.3	1.06	79.35	81.70	36.20	175	9.0	2
16	48.2	1.15	93.15	79.25	38.20	156	9.0	2
17	47.8	1.15	102.83	75.94	36.30	166	9.4	2

RTF Test

Participants	RTF time (min)	Speed (mph)	Ave $\dot{V}O_{2max}$ (ml· min^{-1}· kg^{-1})	Resting Lactate (mM)	End Lactate (mM)	RPE beginning	RPE final	HR Beginning (bpm)	HR End (bpm)
1	44.00	7.9	45.55	2.6	3.5	13	18	155	175
2	60.00	8.1	38.68	2.7	3.1	13	18	168	197
3	20.00	8.4	42.00	2.4	10.3	11	17	159	185
4	47.66	7.8	38.27	1.8	10.5	11	17	150	188
5	61.00	7.3	38.17	2.8	4.7	13	18	163	193
6	30.00	7.5	37.70			13	18	171	188
7	21.00	7.4	41.11	3.0	6.4	11	17	152	180
8	32.00	8.0	44.20	3.0	7.0	11	17	158	175
9	61.00	7.0	37.90	2.0	6.7	11	17	150	170
10	33.00	7.4	36.92	2.0	4.3	11	18	170	190
11	33.00	6.8	36.42	2.4	5.0	12	18	160	176
12	20.00	7.5	38.10	2.9	8.5	13	18	172	198
13	56.00	7.0	36.18	2.6	10.6	12	17	150	172
14	53.33	7.4	34.92	2.4	10.1	10	20	128	166
15	30.00	7.8	35.70	1.2	16.6	10	19	154	199
16	15.00	8.2	41.12	3.4	10.1	13	19	159	198
17	50.00	7.4	38.42	1.0	4.1	9	18	130	180

Appendix E

Article Manuscript

Does Running Time to Fatigue at Ventilatory Threshold predict 5-km Run Time performance in Female Runners?

Tsuri Castel

Department of Sport and Exercise Sciences, Barry Univeristy, Miami Shores, FL

ABSTRACT

Purpose: of the study was to predict 5-km run performance from run time to fatigue at ventilatory threshold (RTF) among a heterogeneous group of female runners. The hypotheses were that RTF will predict 5-km run time and that $\dot{V}O_{2max}$ and RTF will be correlated to one another.

Methods: Seventeen female runners (Mean age = 32.6 ± 8.9 yrs; $\dot{V}O_{2max}$ = 48.09 ± 3.3 $ml \cdot min^{-1} \cdot kg^{-1}$) from south Florida volunteered to take part in the study. They reported a 5-km personal best run time (Mean ± SD; 24.0 ± 2.4 min) and performed an incremental $\dot{V}O_{2max}$ test on a treadmill. Ventilatory threshold (VT) was calculated. On another day, participants performed RTF at the velocity corresponded to VT (*v*VT).

Results: RTF (Mean: 39.2 ± 15.8 min) did not predict 5-km run time (R^2 = .071, $p > .05$) and was not correlated to $\dot{V}O_{2max}$ ($r = .075$, $p > .05$). Significant correlations were demonstrated between $\dot{V}O_{2max}$ and 5-km run time (R^2 =.563, $p > .05$), and between $\dot{V}O_{2max}$ and years of experience as a runner ($r = .535$, $p < .05$).

Conclusion: We concluded that $\dot{V}O_{2max}$, not RTF is the best predictor of 5-km performance among heterogeneous group of recreational female runners and years of training are associated with the improvement in $\dot{V}O_{2max}$.

INTRODUCTION

Successful performance in competitive distance running is related primarily to the athlete's maximal oxygen capacity ($\dot{V}O_{2max}$), which distinguishes between highly-trained and less-trained individuals. However, among a homogenous group of runners where relatively small differences in performance exist, $\dot{V}O_{2max}$ values are similar (6, 11, 19). Other physiological characteristics, such as lactate threshold (LT) and running economy, become more important predictors of performance among these runners (10, 13, 14, 19, 38, 45).

Running time to fatigue (RTF) at $\dot{V}O_{2\,max}$ ($v\dot{V}O_{2max}$) and at LT (*v*LT) were offered as better predictors than either $\dot{V}O_{2max}$ or running economy at a submaximal intensity in a homogeneous group of trained runners, but not in less-trained runners (6, 13, 25). Elite male and female runners did not differ in RTF at $v\dot{V}O_{2max}$ (376 ± 118 vs. 421 ± 129 sec, respectively), although they demonstrated different values of $\dot{V}O_{2max}$ (77.7 ± 6.4 vs. 63.2 ± 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) and velocities (5.8 ± .3 vs. 4.8 ± .2 $m \cdot s^{-1}$, respectively) (3).

The ventilatory threshold (VT) is a determined by a non-invasive method to estimate endurance performance. The VT is related to increase in minute ventilation ($\dot{V}_E$), $\dot{V}O_2$, and $\dot{V}CO_2$, and can be measured in different methods such as the $\dot{V}_E / \dot{V}O_2$ method and the V-Slope method (27, 44).

VT% $\dot{V}O_{2max}$ was lower than the % $\dot{V}O_{2max}$ during marathon race moderately heterogeneous male runners (76.1 ± 5.5% vs. 79.4 ± 5.2% of $\dot{V}O_{2max}$, respectively) (22). However, less is known about performance at VT for shorter distances.
Most studies on VT examined male participants (1, 22, 23, 27, 30, 41). However, lack of information exists about RTF at VT and the differences in VT between trained and less trained females. Further, less trained female runners were usually examined in relation to the effect of the menstrual cycle on $\dot{V}O_{2max}$ and running performance (16, 17, 29, 46). Therefore, the purpose of the study was to determine whether RTF at VT can predict 5-km run performance among heterogeneous group of female runners and to determine whether RTF was associated with $\dot{V}O_{2\,max}$. It was expected that RTF at VT will significantly predict 5-km run times among female runners. It was expected that $\dot{V}O_{2\,max}$ and RTF at VT will be significantly correlated to one another.

METHODS

Participants

Seventeen female runners from South Florida (Descriptive data Table 1) volunteered to take part in the study. They were recruited to participate in the study by flyers that were distributed at 5 and 10-km races in the area. The participants were screened based on their training history, and were included in the study if they had running experience of at least one year, had trained regularly in the 12 months prior the study, had trained at least 3 times per week, had participated in a 5-km race before the study, had trained for a specific 5-km race, had a personal best 5-km time that was less than 30 min and that was set within a year prior the study.

Table 1. Descriptive Data

Participants	Age (yrs)	Body Mass (kg)	Height (cm)	Experience (yrs)	5-km PB (min)
1	25	59.1	168	2	21.08
2	26	68.2	178	10	22.50
3	37	54.5	165	10	21.50
4	26	53.6	165	10	23.00
5	35	59.1	165	5	25.58
6	21	51.4	157	4	25.00
7	36	62.7	168	6	28.00
8	39	65.5	170	10	20.00
9	43	54.5	168	4	21.38
10	45	55.5	165	4	23.91
11	41	65.9	170	1	28.00
12	24	73.6	171	2	27.86
13	45	61.4	163	4	24.00
14	41	62.7	163	7	25.21
15	19	63.2	175	3	24.00
16	30	59.1	163	3	24.00
17	22	65.9	173	2	24.00

Procedure

The participants visited the Human Performance Laboratory at Barry University on two separate days. They were instructed to refrain from training a day before each test and to consume the last meal no less than two hours before the tests. They reported on their training history, and their menstrual cycle status and phase. Body mass was measured in pounds (± .2 kg) using a Health-O-Meter weight scale and height was measured in centimeters (± .1 cm) using a wall-mounted standmeter scale.

Two treadmill running tests were performed on separate days, one to measure $\dot{V}O_{2max}$ and VT and the other to determine RTF at *v*VT.

Maximal Oxygen uptake ($\dot{V}O_2$ max)

An incremental test to exhaustion on a treadmill was performed (Table 2.) Five min of warm-up on the treadmill and 5 to 10 min of rest were given before the beginning of the test. The initial speed corresponded to the warm-up speed, and was rating on the Perceived Exertion (RPE) Borg Scale at 6-7 (6 - 20 scale) (7). The speed was increased by 0.4 mph (miles per hour) every one minute for 10 stages after which only the treadmill grade was increased by 2% every one minute. The participants were encouraged to run until exhaustion.

$\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}_E$ were measured continuously using the Parvo Medics' TrueOne® 2400 metabolic system. O_2 and CO_2 percentages and volume were continuously measured from expired gas collection. The system was calibrated before each test with a known percentage of O_2 and CO_2 and gas volume. RPE was measured using the Borg scale. Heart rate (HR) was monitored continuously using telemetry (Polar™).

$\dot{V}O_{2max}$ value was calculated as the average of the highest last three measures. In addition, it was necessary for one of the following criteria to be met: respiratory exchange ratio ≥ 1.15 or HR over 90% of the age-predicted maximal HR.

Table 2. $\dot{V}O_2$ max Test

Participants	$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	RER max	$\dot{V}_E$ max ($l \cdot min^{-1}$)	$\dot{V}O_{2max}$ at VT ($ml \cdot min^{-1} \cdot kg^{-1}$)	% $\dot{V}O_{2max}$	HR at VT (bpm)	Maximal speed (mph)	Grade (%)
1	53.5	1.15	106.06	78.50	42.00	157	9.5	2
2	51.1	1.13	110.43	77.88	39.80	156	8.5	6
3	54.0	1.17	85.30	75.37	40.70	167	9.6	2
4	50.9	1.17	94.33	74.26	37.80	172	9.0	4
5	47.1	1.17	98.51	79.40	37.40	163	8.5	4
6	47.0	1.15	87.83	74.68	35.10		8.7	4
7	45.5	1.16	98.71	85.49	38.90	157	9.0	0
8	52.2	1.13	126.62	76.00	39.70	155	10.0	0
9	50.4	1.11	93.29	70.60	35.60	155	9.0	2
10	44.2	1.18	95.59	73.30	32.40	178	9.0	2
11	44.0	1.16	94.54	77.50	34.10	156	8.5	0
12	47.0	1.28	115.89	75.59	36.00	166	8.5	4
13	44.5	1.19	88.65	78.65	35.00	149	8.5	2
14	45.9	1.23	95.01	77.77	35.70	150	8.5	2
15	44.3	1.06	79.35	81.70	36.20	175	9.0	2
16	48.2	1.15	93.15	79.25	38.20	156	9.0	2
17	47.8	1.15	102.83	75.94	36.30	166	9.4	2

Ventilatory threshold (VT)

VT was assessed by graphing the results measured during the $\dot{V}O_{2max}$ test for the ventilatory equivalent of oxygen ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$). The point was determined where $\dot{V}_E/\dot{V}O_2$ exhibited a systematic increase without an accompanying rise in the ventilatory equivalent for CO_2 ($\dot{V}_E/\dot{V}CO_2$) (15). Two different observers determined the VT independently of each other. When disagreement occurred, a third observer, who was approved by both of the observers, verified the VT using the same method. The corresponding velocity (*v*VT) was determined based on the treadmill speed (15, 43). Figure 1 depicts an example of the ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) and CO_2 ($\dot{V}_E/\dot{V}CO_2$) and the point at which VT occurs (arrow).

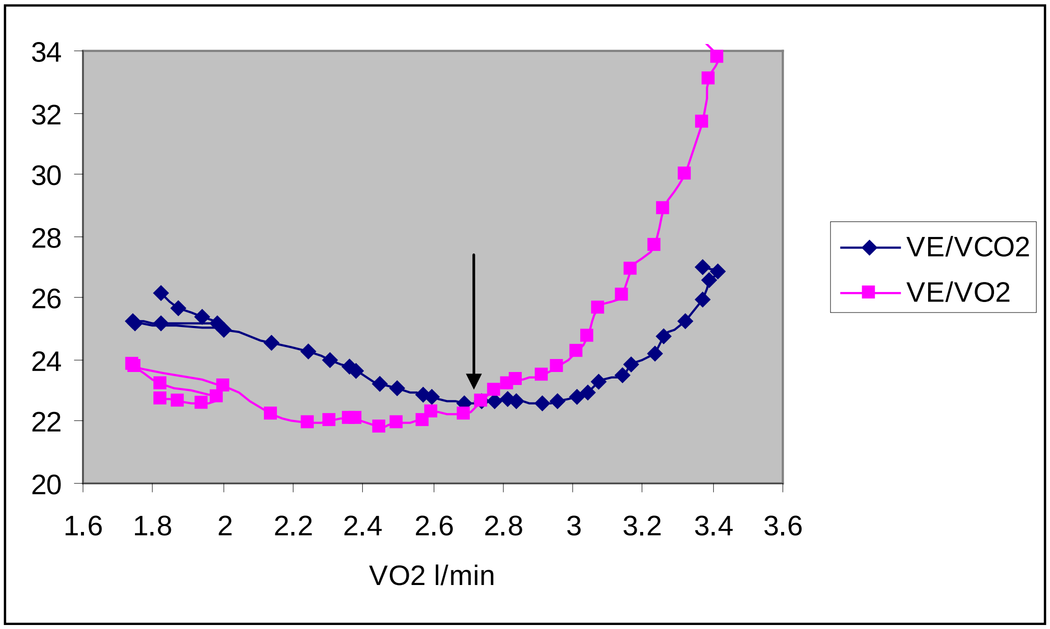

Figure 1. The Relationship Between $\dot{V}O_2$ and the Ventilatory Equivalent for O_2 ($\dot{V}_E / \dot{V}O_2$) and CO_2 ($\dot{V}_E / \dot{V}CO_2$).

Run time to fatigue (RTF) at *v*VT

For the RTF test, runners were instructed to run until voluntary fatigue (Table 3). After a 5-min warm-up and a short time to rest, the speed was increased in less than 15 sec to the *v*VT. Participants continued running at *v*VT until fatigue. During the first 5 min of the run, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$ and HR were continuously measured as described above. Following the initial 5 min HR and RPE was measured every 5 min.

Blood lactate was measured by a portable lactate *Accusport* analyzer from blood taken by finger stick at rest and immediately upon stopping the exercise. Participants were not provided encouragement by the investigator and were notified about the running speed only before the warm-up. The participants were allowed to wear a music set during the run.

Table 3. RTF Test

Participants	RTF time (min)	Speed (mph)	Ave $\dot{V}O_{2max}$ (ml·min^{-1}·kg^{-1})	Resting Lactate (mM)	End Lactate (mM)	RPE beginning	RPE final	HR Beginning (bpm)	HR End (bpm)
1	44.00	7.9	45.55	2.6	3.5	13	18	155	175
2	60.00	8.1	38.68	2.7	3.1	13	18	168	197
3	20.00	8.4	42.00	2.4	10.3	11	17	159	185
4	47.66	7.8	38.27	1.8	10.5	11	17	150	188
5	61.00	7.3	38.17	2.8	4.7	13	18	163	193
6	30.00	7.5	37.70			13	18	171	188
7	21.00	7.4	41.11	3.0	6.4	11	17	152	180
8	32.00	8.0	44.20	3.0	7.0	11	17	158	175
9	61.00	7.0	37.90	2.0	6.7	11	17	150	170
10	33.00	7.4	36.92	2.0	4.3	11	18	170	190
11	33.00	6.8	36.42	2.4	5.0	12	18	160	176
12	20.00	7.5	38.10	2.9	8.5	13	18	172	198
13	56.00	7.0	36.18	2.6	10.6	12	17	150	172
14	53.33	7.4	34.92	2.4	10.1	10	20	128	166
15	30.00	7.8	35.70	1.2	16.6	10	19	154	199
16	15.00	8.2	41.12	3.4	10.1	13	19	159	198
17	50.00	7.4	38.42	1.0	4.1	9	18	130	180

Statistical Analysis

A simple linear regression was calculated predicting 5-km run time from RTF at *v*VT. Additional simple linear regression was calculated for the relationship between RTF at VT and $\dot{V}O_{2max}$. All data were presented as mean ± SD. Significance was set at $p \leq .05$.

RESULTS

$\dot{V}O_2$ max Test

$\dot{V}O_{2max}$ test data, including maximal and VT, are presented in Table 4. The criteria used for determining $\dot{V}O_{2max}$ were constant (plateau)values of $\dot{V}O_2$ during the last stage of the incremental $\dot{V}O_{2max}$ test, respiratory exchange ratio ≥ 1.15, and HR over 90% of the age predicted maximal HR. The test was terminated because of voluntary fatigue.

Table 4. Results of the $\dot{V}O_2$ max Test.

	Mean	SD	Range
$\dot{V}O_{2max}$ (ml· min^{-1}· kg^{-1})	48.1	3.3	44.0 – 54.0
$\dot{V}_E$ max (l· min^{-1})	98.0	11.6	79.3 – 126.6
RERmax	1.16	.04	1.06 -1.28
HRmax (bpm)	184	9	166 - 199
$\dot{V}O_{2max}$ at VT (ml· min^{-1}· kg^{-1})	37.1	2.5	32.4 – 42.0
% $\dot{V}O_{2max}$ at VT	77.1	3.4	70.6 – 85.4
HR at VT (bpm)	161	9	149 - 168

RTF Test

RTF data are presented in Table 5. Mean running speed was 7.58 ± .44 mph with a range of 6.8 to 8.4 mph. Mean RTF was 39.2 ± 15.8 min with a range of 15.0 to 61.0 min. Heart rate, RPE and blood lactate were measured during the first 5 minutes and again immediately following the test.

Table 5. Results of the RTF test.*

	Mean	SD	Range
$\dot{V}O_2$ (ml· min^{-1}· kg^{-1})	38.9	3.0	34.9 – 45.5
% $\dot{V}O_{2max}$	81.3	4.4	75.1 – 90.3
$\dot{V}_E$ (l· min^{-1})	67.8	9.2	56.9 – 92.5
HR beg (bpm)	169	9	153 – 185
HR end (bpm)	184	11	164 - 203
Lactate beg (mMol)	2.3	.7	1.0 – 3.4
Lactate end (mMol)	7.5	3.6	3.1 – 16.6
RPE beg	11.5	1.2	9 - 13
RPE end	18.5	.8	17 - 20

* Heart rate, lactate and RPE were recorded at the beginning (beg) and end of the test.

Performance Predictors

A simple linear regression was calculated to predict 5-km run time from RTF. RTF did not predict 5-km run performance ($F_{(1, 15)} = 1.147$, $p > .05$) with an $R^2 = .071$.

A Pearson correlation coefficient was calculated for the relationship between $\dot{V}O_{2max}$ and RTF. There was no significant correlation between $\dot{V}O_{2max}$ and RTF ($r(15) = .075$, $p > .05$).

Unexpectedly, $\dot{V}O_{2max}$ significantly predicted 5-km run performance ($F_{(1, 15)} = 19.363$, $p < .001$) with an $R^2 = .563$. The relationship is presented in figure 2. Furthermore, a strong positive correlation was found by calculating a Pearson correlation coefficient for the relationship between $\dot{V}O_{2max}$ and years of experience ($r(15) = .535$, $p < .05$). The relationship is presented in figure 3. Additional Pearson correlation coefficient calculation found a strong correlation coefficient for the relationship between $\dot{V}O_{2max}$ and $\dot{V}O_2$ at VT ($r(15) = .804$, $p < .05$). This relationship led to additional significant correlation coefficient between $\dot{V}O_{2max}$ and running speed during the RTF test ($r(15) = .659$, $p < .05$).

A significant regression equation was found between 5-km run performance and running speed during the RTF test ($F_{(1, 15)} = 5.658$, $p < .05$) with an $R^2 = .274$. This relationship is presented in figure 4.

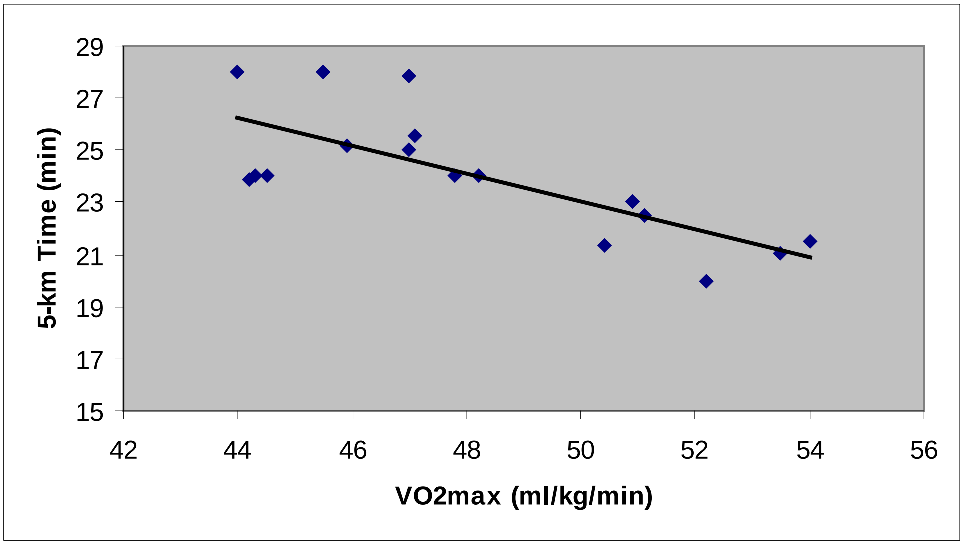

Figure 2. The relationship between 5-km run time and $\dot{V}O_2$ max.

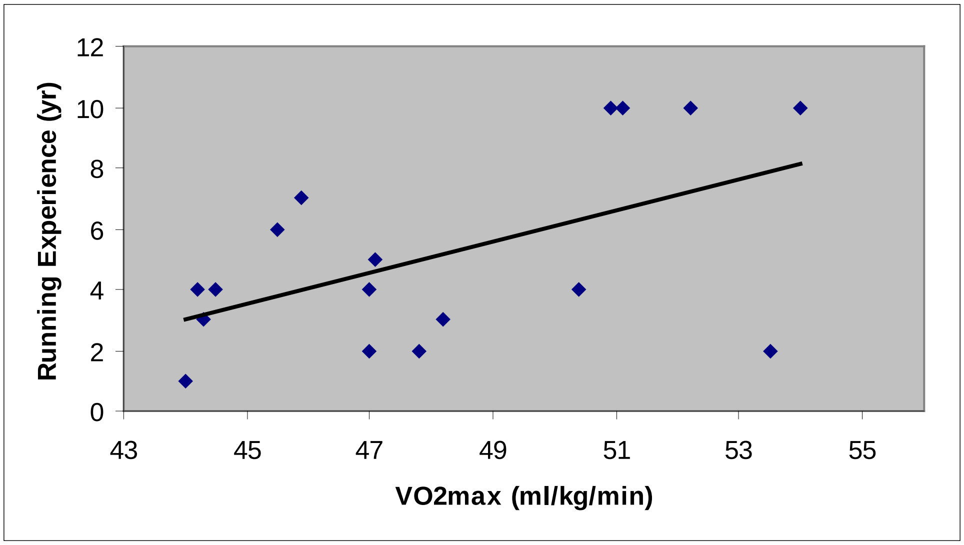

Figure 3. The relationship between years of experience and $\dot{V}O_2$ max.

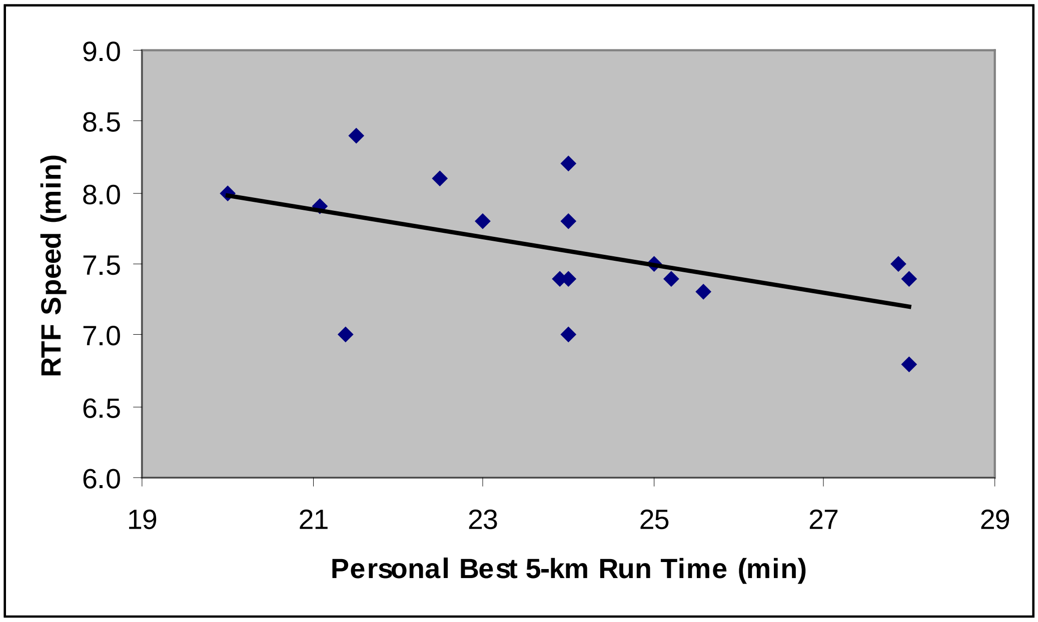

Figure 4. The relationship between RTF speed and 5-km run time.

DISCUSSION

The purpose of the study was to predict 5-km run performance from RTF at VT among heterogeneous group of female runners. The hypotheses were that RTF at VT will predict 5-km run time and that $\dot{V}O_{2max}$ and RTF will be correlated to one another.

While most studies sought to predict running performance among heterogeneous groups of male athletes, examine gender differences or test homogeneous groups of males, this study examined running performance among a heterogeneous group of recreational long distance female runners. This group may represent the majority of long distance female runners in South Florida who participate in road races but do not train according to a designed program or with coaching assistance.

Running time to fatigue has been used to predict distance running performance at velocities such as $v\dot{V}O_{2max}$ and velocities associated with blood lactate levels of 2mM and 4mM (2, 6, 10, 36, 46). At these velocities RTF was correlated to running performance in distances from 3 to 21.1-km in homogeneous groups of runners. We examined the run time to fatigue among runners who sustained submaximal steady state $\dot{V}O_2$ corresponding to VT

Run Time to Fatigue as a Performance Predictor

The essential result of the study was that RTF at VT did not predict 5-km run time among a heterogeneous group of long distance female runners. The reason may be related to differences in performance during road race and on a treadmill. Farrell and colleagues showed that experienced marathon runners demonstrated a marathon race pace that was 3 to 7 m/min faster than the speed associated with the level of onset of blood lactate accumulation (OBLA) (20). The authors suggested that the treadmill data may underestimate the energy cost associated with the road race conditions. The participants may run at a higher fractional of their $\dot{V}O_{2max}$ during a race than that was measured from treadmill data because of varying conditions, such as training, environmental factors, and experience. In addition, events such as road races that include other runners and spectator may increase the runners' motivation to run faster compared to run by themselves on a treadmill in lab conditions.

Another reason for the fact the RTF at VT did not predict 5-km run may be that 5-km requires a higher percentage of anaerobic capacity than the *v*VT. Although, 5-km run is considered a long distance, it is performed at a higher percentage of anaerobic capacity compared to other longer distances such as 10-km or marathon (21, 34). During 5-km run, approximately12.5% of the ATP is provided by anaerobic glycolysis and 87.5% by aerobic processes. For 10-km and a marathon run, the anaerobic glycolysis pathway provides about 3% and 0% of the ATP, respectively and the aerobic pathway provides 97% and 100% of the ATP, respectively (34). Therefore, fatigue in 5-km may be because of accumulation of lactic acid. This was demonstrated in the present study, when blood lactate level was significantly increased from resting level to the end of the RTF (Mean: 2.3 ± .2 to 7.5 ± .9 mM). However, the participants in the present study trained to participate in road races of duration ranged from 5-km to a marathon. Their training method consisted mostly of long distance runs at low to moderate intensities. For this reason they demonstrated different abilities to maintain the speed at the RTF test. For instance, the participant who reported the fastest 5-km personal best time (20 min), trained during the course of the data collection for the Hawaiian Iron-Man triathlon. She reduced the amount of high intensity interval training and increased the weekly mileage at low intensities. This may be the reason for her difficulties to sustain the RTF at VT longer than 32 min, which was below the group average of 39.23 ± 15.86 min.

Interestingly, nine participants were able to sustain the *v*VT for a longer time than the 5-km personal best run time. Surprisingly, the *v*VT of these runners was similar to or faster than their 5-km personal best. This may be because the participants in this study probably underestimated their running abilities. Most of them participated in road races in a purpose of completing the distance, performing better than other women or running faster than other women at their age group. Most of them did not challenge themselves to run faster in order to improve their personal best times. However, in the RTF test, the pace was set and the runners were acknowledged that they were not expected to reach a certain time or duration. These facts probably reduced their anxiety from the test and may increase their motivation to accumulate running time.

Their ability to run faster and longer than their 5-km personal best may be also related to inherited physiological factors, such as type of muscle fibers, amount of aerobic and anaerobic enzymes and the ability to sustain increase in lactic acid in the muscles (10, 46). The importance inherited physiological abilities was shown in black and Caucasian long runners with similar $\dot{V}O_{2max}$ values (61.9 ± 5.9 vs. 65.2 ± 7.2 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively), who were examined in their ability to run until fatigue at 72, 80, 88, and 92% of each individual peak treadmill velocity that was measured during a $\dot{V}O_{2max}$ test (46). The black runners had significantly better results in the following measurements compared to the Caucasian runners: 21% longer time to fatigue, blood lactate accumulation that was lower in 38% and 50% higher level of oxidative enzymes, but no correlation was found between $\dot{V}O_{2max}$ and RTF. Although, the participants in the present study demonstrated heterogeneous values of $\dot{V}O_{2max}$, no significant relationship was found between RTF and $\dot{V}O_{2max}$ as well.

The reason that RTF and $\dot{V}O_{2max}$ were not correlated to one another in the present study may be attributed to the fact that the runners trained for a large range of distances from 5-km to a marathon and their trainings were performed at low to moderate intensities. Their $\dot{V}O_{2max}$ value was increased as a result of these training. However, success in RTF may be related to specific training for a certain distance in order to gain fatigue resistance against specific fatigue mechanism (1, 2, 3, 4, 5, 10, 22, 38, 46). For instance, the participant who demonstrated the highest $\dot{V}O_{2max}$ (54.0 $ml \cdot kg^{-1} \cdot min^{-1}$), trained during the course of the data collection for the Chicago Marathon and therefore, reduced the amount of high intensity interval training and increased her weekly mileage at low intensities (< 70% $\dot{V}O_{2max}$). For this reason, she ran the RTF at VT in 20 min which was less than the group average. The effect of different training methods was also shown when middle distance runners who had similar $\dot{V}O_{2max}$ as long distance runners (72.7 ± 5.6 vs. 73.4 ± 4.6 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) were tested (2). The middle distance runners were able to run longer at $v\dot{V}O_{2max}$ than the long distance runners (16.2 ± 3.8 vs. 14.0 ± 2.1 min, respectively) because they trained at velocities that were closer to their $\dot{V}O_{2max}$ compared to the long distance runners who trained at lower intensities (2).

$\dot{V}O_2$ max as a Predictor of 5-km

$\dot{V}O_{2max}$ significantly predicted 5-km run performance and a significant correlation was shown between *v*VT and 5-km run time. The group of athletes demonstrated a wide range of 5-km times and $\dot{V}O_{2max}$ values. There was a 16% difference in $\dot{V}O_{2max}$ between the higher and lower values and 15% difference between the fastest and the slowest times. Traditionally, $\dot{V}O_{2max}$ has been considered an important determinant for success in long distance events in heterogeneous runners (4,14, 21, 23). In addition, $\dot{V}O_{2max}$ increases as a result of both long duration training at a moderate pace and interval training (24, 42). Our data are similar to a previous study that showed that $\dot{V}O_{2max}$ was highly correlated with 5-km, 10-km, and 16.09 running pace (r = .91, r = .92, r = .88, respectively). The runners in that study were moderately to highly-trained female runners who had comparable characteristics to the present study such as moderate variability of $\dot{V}O_{2max}$ (59.7 ± 5.3 $ml \cdot kg^{-1} \cdot min^{-1}$), and at least one year of running experiences (21).

Speed of running at $\dot{V}O_{2max}$ or lactate threshold has been correlated with performance (4, 6, 10, 39, 46). In the present study, *v*VT was correlated to 5-km run time. However, the results are not surprising because with the increase in $\dot{V}O_{2max}$, there was an increase in the absolute value of $\dot{V}O_2$ at VT and therefore a faster *v*VT. Poole and Geasser showed that $\dot{V}O_{2max}$ and VT increased in three groups of runners who trained for 8 weeks 3 d/wk at low intensity exercise (55 min at 50% $\dot{V}O_{2max}$), moderate exercise intensity (35 min at 70% $\dot{V}O_{2max}$), or high intensity exercise (10 bouts of 2 min at 105% $\dot{V}O_{2max}$) (24). However, $\dot{V}O_{2max}$ increased significantly in all group with no differences between groups, whereas, the greatest increase in VT was in the group who trained at high intensity.

In the present study, the relationship between $\dot{V}O_{2max}$ and running performance may very well be related to years of experience. Three of the four runners who demonstrated the highest $\dot{V}O_{2max,}$ had 10 years of experience. This is likely so participants who had more years of experience train to improve their running ability by raising the duration of the runs and incorporating high intensity intervals runs in their training compared to the runners who had less years of experience and ran at low to moderate intensities. Furthermore, the experienced runners raised the challenge with the years by racing in longer distances or running faster at the same distances in order to improve personal best run times. In contrast, the less experienced runners reported that their main goal is to finish the race and not to improve their running times. Therefore, they trained and raced at low to moderate exercise intensities which may result in lower $\dot{V}O_{2max,}$ $\dot{V}O_2$ at VT, and *v*VT than the experienced runner.

Practical Application

$\dot{V}O_{2max}$ is a good predictor in heterogeneous groups of runners. Although, the value of $\dot{V}O_{2max}$ depends mostly on heredity, it increases with the progression of training (duration and intensity) and can be increased by 5-15% (41). For this reason, recreational female runners should increase duration and intensity of training in order to reach a higher potential of their $\dot{V}O_{2max}$. However, in order to improve fatigue resistance, recreational female runners should train at velocities similar to the speed they intend to run during road races.

The importance of training methods to improve fatigue resistance at a specific distance is shown in highly trained homogeneous group of runners who are already close to their highest potential of $\dot{V}O_{2max}$. In this group, the most successful athletes are those who can sustain a given velocity and high percentage of $\dot{V}O_{2max}$ during racing at any distance because they have superior fatigue resistance. Therefore, athletes should include training at a velocity similar to the pace they intend to run during races. This will increase their fatigue resistance against a specific fatigue mechanism. They also should be challenged to run faster during road races in a purpose of improving personal best

Conclusion

RTF at VT does not predict 5-km time among a heterogeneous group of recreational long distance female runners. This is mainly for the reason that the participants were not considered 5-km specialists. They trained for long duration at a low to moderate intensity which increases resistance to fatigue mechanism that associated with reduction in blood glucose level. However, 5-km run consist of high percentage of anaerobic capacity that results in other fatigue mechanism such as increase in lactic acid in the muscles. In addition, treadmill run may underestimate the energy cost associated with road race conditions.

As was established in previous studies, this study showed that $\dot{V}O_{2max}$ is the best predictor for success in endurance events in a heterogeneous group of runners. $\dot{V}O_{2max}$ was correlated to VT, *v*VT, 5-km run performance and years of experience but was not correlated to RTF at VT. The reason for these results may be attributed to the fact that

$\dot{V}O_{2max}$ increases with training in both low to moderate and high training intensities. However, in order to improve ability to sustain run until fatigue at a given speed, a runner should train at a similar speed.

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