

**EFFECTS OF INTERINDIVIDUAL VARIATION, STATE OF TRAINING,
AND PROLONGED WORK ON RUNNING ECONOMY**

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Abstract. The purpose of this study was to examine running economy differences between a group of well-trained runners and a group of non-runners. A secondary objective was to ascertain the effects of a prolonged run, near the ventilatory threshold, on running economy. Two groups of ten males [Mean±SD: age 25.6±4.8 yrs, $\dot{V}O_{2\max}$ 70.9±6.3 ml·kg⁻¹·min⁻¹ for the runners; age 20.6±2.3 yrs, $\dot{V}O_{2\max}$ 51.5±1.9 ml·kg⁻¹·min⁻¹ for the non-runners] performed 2 running economy tests (speeds = 2.68 m·s⁻¹ and near T_{vent}) on 3 occasions prior to a prolonged run. Secondly, a prolonged run (maximum of 60 min) near the subject's individual ventilatory threshold was performed and followed by 2 running economy tests at the same speeds. Despite the statistically significant difference in $\dot{V}O_{2\max}$ (p<0.05), the groups did not differ significantly in their running economy. As well, no statistically significant differences were found when running economy was measured as a function of distance (ml·kg⁻¹·km⁻¹) and when body mass was scaled to an exponent of 0.75 (ml·kg^{-0.75}·min⁻¹, ml·kg^{-0.75}·km⁻¹). The prolonged run had no statistically significant effects on the running economy of either group. The results from this study indicate, despite a marked difference in training status between the groups, there were no running economy differences. Further, the effects of a prolonged run near the ventilatory threshold were of insufficient duration and/or intensity to significantly perturb the running economy of either group.

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Introduction

Running economy (RE), defined as the steady-state oxygen consumption ($\dot{V}O_2$) for a given running velocity, has received considerable attention in the literature. Numerous factors that affect RE include: intra-individual variability, gender, age, treadmill versus overground running, fatigue, training status, as well as biomechanical considerations [21]. Running economy is typically quantified by measuring the steady-state $\dot{V}O_2$, expressed with respect to body mass and time, for a standardized, submaximal running speed [21] and represents the aerobic demand of running at that particular speed.

Running economy has been shown to account for a large proportion of the variability in distance running performance among runners similar in $\dot{V}O_{2\max}$ [9]. Within an elite group of distance runners homogeneous for $\dot{V}O_{2\max}$, 65.4% of the variation observed in 10 km race performance could be explained by variation in RE. Due to the variability in RE between individuals [24], results are still inconclusive as to whether trained individuals are always more economical than their untrained counterparts. As RE seems to account for a large proportion of the variation in distance running performance, understanding the differences in RE between individuals is important to understanding the degree to which it can be altered, as well as guiding future studies attempting to improve RE. Fatigue, induced by long duration exercise, has adversely influenced RE in some studies [6,8,21] while others have shown no alteration in RE [14,22,24]. How fatigue affects individuals of different training status (trained vs. untrained) has yet to be determined.

The purpose of this study is to examine variation in running economy. Differences in running economy will be examined in a group of well-trained runners versus a group of non-runners. As well, variation in running economy will be measured in the two groups after a prolonged run near the ventilatory threshold.

Materials and Methods

Subjects: Two groups of 10 subjects were selected for this study. One group consisted of trained male runners (Vm70) while a second group consisted of male non-runners (Vm50). The Vm50 group were classified as relatively untrained, non-running males with $\dot{V}O_{2\max}$ values less than $55 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, while the Vm70 group were classified as well-trained males with $\dot{V}O_{2\max}$ values greater than $65 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Before testing, all risks were thoroughly explained to the subjects and their written informed consent was obtained in accordance with the Guidelines for Ethical Review at the University of British Columbia.



Experimental protocol: Subjects completed 5 separate days of laboratory testing. The first test day consisted of descriptive measures and a $\dot{V}O_{2\max}$ test. The next three testing days were identical with subjects performing two 10-minute running economy (RE) tests. These sessions were used to generate the “pre” long run values for RE. The final testing day consisted of a prolonged run near the ventilatory threshold followed by another 2 RE tests. This session generated the “post” long run values for RE.

a. Preliminary testing: Age, height, body mass, and sum of 5 skinfolds (S5SF: biceps, triceps, subscapular, iliac crest, and medial calf) were recorded. Subjects performed a $\dot{V}O_{2\max}$ test on a Quinton treadmill while expired gases were collected and analyzed using a Vmax metabolic measurement cart (SensorMedics, 29 Series). Heart rate was measured using a portable telemetry unit (Polar Vantage NV, Polar Electronics, Port Washington, N.Y., USA). All sessions were preceded with an explanation of the testing procedures followed by a light 5-minute warm-up. $\dot{V}O_{2\max}$ testing began at $2.24 \text{ m}\cdot\text{s}^{-1}$ (5 mph) for the Vm50 group and at $2.68 \text{ m}\cdot\text{s}^{-1}$ (6 mph) for the Vm70 group. In both groups increases of $0.22 \text{ m}\cdot\text{s}^{-1}$ (0.5 mph) occurred every minute until $4.47 \text{ m}\cdot\text{s}^{-1}$ (10 mph) was reached, after which a grade increase of 2% occurred every minute until volitional exhaustion. A $\dot{V}O_{2\max}$ test was considered acceptable if the subject met the following 3 criteria: (1) a plateau (defined as an increase of no greater than $2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ during the final stage of the test) or slight decrease in $\dot{V}O_2$, (2) an RER greater than 1.10, (3) a heart rate within 10% of the age predicted maximum. Two experienced exercise physiologists determined each subject’s ventilatory threshold (T_{vent}) using visual inspection of the excess carbon dioxide elimination curve [15].

b. “Pre” running economy tests: Subjects performed a five-minute warm-up run followed by two ten-minute RE tests. The velocities for the RE tests were as follows: (1) an absolute measure of $2.68 \text{ m}\cdot\text{s}^{-1}$, (2) a relative measure corresponding to the subject’s velocity at T_{vent} minus $0.22 \text{ m}\cdot\text{s}^{-1}$. The two velocities were randomized to reduce any order effect, and 10 minutes of rest was allocated between each. Expired gases were analyzed during the final 4 minutes of each running economy test using the same metabolic measurement cart as the $\dot{V}O_{2\max}$ test. RE was calculated by averaging the values obtained in the final 4 minutes of the test, a method previously used by Morgan *et al.* [22]. Once RE data was generated for the 3 sessions an average was taken to represent the “pre” running economy.

c. Prolonged run and “post” running economy tests: Subjects performed a prolonged run of up to 60 minutes on the treadmill at a velocity that corresponded to their respective ventilatory thresholds minus $0.22 \text{ m}\cdot\text{s}^{-1}$. Body mass was record



immediately before and after the run to determine any weight loss. Two 6-minute RE tests were performed no later than 10 minutes following the prolonged run. These two tests were identical to the “pre” RE testing in terms of the equipment used and the speeds selected. The order of velocities was again randomized and RE was calculated by averaging the $\dot{V}O_2$ during the last three minutes of each bout and reported as the “post” RE.

Statistical analysis: An analysis of variance was used to evaluate HR, ventilatory threshold (T_{vent}), $\dot{V}O_2$, RE ($\dot{V}O_{2sub\ max}$), \dot{V}_E , and RER. A 2x2 repeated measures ANOVA examined the effects of the prolonged run on these same variables. All tests were run on SPSS 10.0 for Windows and were standardized for a statistical significance level of $p < 0.05$.

Results

Selected physical and metabolic characteristics for the subjects are shown in Table 1. While analysis of variance revealed that the groups were similar in height and body mass, the Vm70 group was older, and had a smaller sum of five skinfolds than the Vm50 group. The Vm70 group possessed significantly higher $\dot{V}O_{2\ max}$ values ($70.9 \pm 6.3 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ vs. $51.6 \pm 1.9 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) when compared to the Vm50 group. Both groups were found to have similar maximum heart rates.

Table 1

Physical and metabolic characteristics for subjects (mean \pm SD)

Variable	Vm70 (n=10)	Vm50 (n=10)	
Age (yrs)	25.6 \pm 4.8	20.6 \pm 2.3	*
Height (cm)	175.1 \pm 6.3	178.5 \pm 7.3	
Weight (kg)	68.1 \pm 6.6	75.7 \pm 10.8	
S5SF (mm)	30.5 \pm 5.6	43.5 \pm 16.0	*
$\dot{V}O_{2\ max}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	70.9 \pm 6.3	51.6 \pm 1.9	*
$\dot{V}O_{2\ max}$ ($\text{L} \cdot \text{min}^{-1}$)	4.8 \pm 0.7	3.9 \pm 0.5	*
$HR_{\ max}$ ($\text{beats} \cdot \text{min}^{-1}$)	186.5 \pm 10.3	191.8 \pm 8.4	

*significant difference ($p < 0.05$) between groups



A comparison of “pre” running economy values ($\dot{V}O_{2\text{submax}}$) between the groups at an absolute speed ($2.68 \text{ m}\cdot\text{s}^{-1}$) are shown in Table 2. At this workload the Vm50 group had a significantly higher RER, minute ventilation, and heart rate. Despite the fact that the Vm50 group had significantly higher minute ventilation

Table 2

Running economy ($\dot{V}O_{2\text{submax}}$) and other selected physiological measures at $2.68 \text{ m}\cdot\text{s}^{-1}$ (mean \pm SD)

Variable	Vm70 (n=10)	Vm50 (n=10)	
RER	0.88 \pm 0.05	0.96 \pm 0.03	*
$\dot{V}O_{2\text{submax}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	37.5 \pm 2.5	38.1 \pm 2.1	
$\dot{V}O_{2\text{submax}}$ ($\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$)	107.8 \pm 6.6	112.1 \pm 7.1	
$\dot{V}O_{2\text{submax}}$ ($\text{L}\cdot\text{min}^{-1}$)	2.57 \pm 0.25	2.88 \pm 0.44	
$\dot{V}O_{2\text{submax}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$)	232.8 \pm 15.3	236.7 \pm 13.3	
$\dot{V}O_{2\text{submax}}$ ($\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{km}^{-1}$)	669.5 \pm 41.2	696.2 \pm 44.3	
\dot{V}_E ($\text{L}\cdot\text{min}^{-1}$)	47.4 \pm 7.2	62.9 \pm 11.8	*
HR ($\text{beats}\cdot\text{min}^{-1}$)	126.3 \pm 12.8	159.8 \pm 14.4	*

*significant difference ($p<0.05$) between groups

(\dot{V}_E) the groups did not differ in their $\dot{V}O_{2\text{submax}}$ oxygen consumption (both absolute ($\text{L}\cdot\text{min}^{-1}$) and relative ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)). In order to remove the effect of significant differences in body composition, the running economy of the groups were compared using allometric scaling measured in $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$ and $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{km}^{-1}$ [2]. No significant differences were found.

A comparison of “pre” running economy values between the groups at a workload corresponding to the subject’s individual near ventilatory threshold (T_{vent}) are displayed in Table 3. At this relative load, the Vm50 group had a higher RER and heart rate, but the speed at which the group ran was significantly slower than the Vm70 group. The Vm70 group was working at a higher $\dot{V}O_{2\text{submax}}$ than the Vm50 group, but when the cost of running (measured in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$) was



compared, there were no significant differences found between the groups. This was also true when the groups were compared using allometric scaling.

The effects of a prolonged run on running economy and other selected physiological variables at a velocity designed to elicit near T_{vent} are displayed in Tables 4 and 5. The Vm70 group all completed the 60 minutes time while the time for the Vm50 group were 43.7 ± 10.9 minutes. The weight loss pre and post prolonged run were nonsignificant with an average loss of 1.1 ± 0.5 kg (range: 0.2-1.8 kg) for the Vm70 group and 0.6 ± 0.5 kg (range: 0.1-1.3 kg) for the Vm50 group. Note that there was one drop out in the Vm50 group reducing the test numbers to 9. In the Vm70 group there was an equipment problem resulting in a lost of data for the "post" RE test at near T_{vent} . Thus, subject numbers in tables 4 and 5 have been changed to reflect these factors.

Table 3

Running economy ($\dot{V}O_{2submax}$) and other physiological measures at near T_{vent} velocity (mean \pm SD)

Variable	Vm70 (n=10)	Vm50 (n=10)	
RER	0.93 ± 0.05	1.00 ± 0.03	*
$\dot{V}O_{2submax}$ (ml·kg ⁻¹ ·min ⁻¹)	53.7 ± 4.4	43.4 ± 2.3	*
$\dot{V}O_{2submax}$ (ml·kg ^{-0.75} ·min ⁻¹)	154.0 ± 12.6	127.3 ± 5.6	*
$\dot{V}O_{2submax}$ (L·min ⁻¹)	3.68 ± 0.45	3.26 ± 0.39	*
$\dot{V}O_{2submax}$ (ml·kg ⁻¹ ·km ⁻¹)	232.9 ± 14.3	232.8 ± 12.2	
$\dot{V}O_{2submax}$ (ml·kg ^{-0.75} ·km ⁻¹)	667.4 ± 38.6	683.3 ± 34.5	
\dot{V}_E (L·min ⁻¹)	75.6 ± 16.0	76.1 ± 11.3	
HR (beats·min ⁻¹)	159.7 ± 12.4	173.6 ± 12.9	*
Speed (m·s ⁻¹)	3.85 ± 0.23	3.11 ± 0.12	*

*significant difference (p<0.05) between groups



Table 4The effects of a prolonged run on running economy at 2.68 m·s⁻¹ (mean±SD)

Variable	Vm70 pre (n=10)	Vm70 post (n=10)	Vm50 pre (n=9)	Vm50 post (n=9)
RER	0.88 ±0.05*	0.78 ±0.06	0.96 ±0.04*	0.89 ±0.06
$\dot{V}O_{2sub\ max}$ (ml·kg ⁻¹ ·min ⁻¹)	37.5 ±2.5	37.6 ±2.2	38.0 ±2.2	38.4 ±3.4
$\dot{V}O_{2sub\ max}$ (ml·kg ^{-0.75} ·min ⁻¹)	107.8 ±6.6	107.7 ±5.9	112.1 ±7.5	113.2 ±9.4
$\dot{V}O_{2sub\ max}$ (l·min ⁻¹)	2.57 ±0.25	2.51 ±0.25	2.92 ±0.45	2.91 ±0.39
\dot{V}_E (l·min ⁻¹)	47.4 ±7.2	48.1 ±7.7	64.3 ±11.6	67.3 ±11.5
HR (beats·min ⁻¹)	126.3 ±12.8	139.8 ±16.7	161.4 ±14.3	166.4 ±14.8

*significant difference (p<0.05) between pre and post

Table 5The effects of a prolonged run on running economy at T_{vent} (mean±SD)

Variable	Vm70 pre (n=9)	Vm70 post (n=9)	Vm50 pre (n=9)	Vm50 post (n=9)
RER	0.92±0.05	0.86±0.04	1.00±0.03	0.97±0.06
$\dot{V}O_{2sub\ max}$ (ml·kg ⁻¹ ·min ⁻¹)	53.3±4.5	53.6±4.7	43.2±2.4	42.9±2.9
$\dot{V}O_{2sub\ max}$ (ml·kg ^{-0.75} ·min ⁻¹)	153.2±13.0	152.7±14.7	127.2±5.9	126.5±7.0
$\dot{V}O_{2sub\ max}$ (l·min ⁻¹)	3.67±0.48	3.58±0.52	3.30±0.39	3.25±0.37
$\dot{V}O_{2sub\ max}$ (ml·kg ⁻¹ ·km ⁻¹)	232.3±15.0	233.6±13.3	231.9±12.6	230.4±16.7
$\dot{V}O_{2sub\ max}$ (ml·kg ^{-0.75} ·km ⁻¹)	667.2±40.9	664.7±37.7	683.5±36.6	680.0±47.0
\dot{V}_E (L·min ⁻¹)	73.9±16.0	72.0±12.4	78.0±10.3	82.4±11.7
HR (beats·min ⁻¹)	161.2±12.1	165.8±15.5	175.3±12.5	174.5±12.8



The prolonged run did not seem to affect the “post” running economy of either group at either of the two velocities. The only variable that was significantly different (from the RE pre tests to the post run tests) was the RER at 2.68 m·s⁻¹. This variable was lower following the prolonged run for both groups. The HR during the post RE test was elevated from the pre RE tests, but the difference was not significant. This was true for both groups.

Discussion

There were no statistical differences between the two groups in running economy at 2.68 m·s⁻¹. While this finding is in accordance with some studies where running economy was equivalent in the trained vs. untrained state [13,29] it is in conflict with others [4,9,10,24,26]. In a recent review, Berg [2] stated that running economy appears to be multifactorial, with possible determinants including the following: skill or biomechanics, training velocity, muscle fiber type, $\dot{V}O_{2\max}$, substrate utilization, muscle power, and flexibility. Perhaps this complexity is the reason for the variability in running economy observed even in highly trained runners [9]. Svedenhag and Sjodin [28] found that economy varied by as much as 30% in trained runners. In the present study, the Vm70 group varied in economy at 2.68 m·s⁻¹ by as much as 17% and the Vm50 group varied up to 16%.

Measuring running economy in ml·kg⁻¹·min⁻¹ may not be entirely acceptable. Both actual mechanical work performed and substrate utilization are not accounted for in a ml·kg⁻¹·min⁻¹ measure. Some runners could be producing more horizontal force while running at a given submaximal $\dot{V}O_2$. It is possible that the more fit runners in the Vm70 group were able to utilize greater fat metabolism as they had a significantly lower RER. This may be beneficial in long duration events such as the marathon as a greater utilization of fat as a substrate would promote the sparing of glycogen stores [2].

Daniels and Daniels [11] looked at the economy of elite male and female runners of varying distances and found that at marathon pace, the marathon runners were more economical than the middle distance runners. However the opposite was also true; at middle-distance pace the 800m and 1500m specialists were more economical. Running economy may not be independent of speed as had been earlier suggested [7]. Daniels and Daniels [11] found that out of 65 elite male and female runners 16 had equal aerobic demands over all speeds tested and 6 had lower $\dot{V}O_2$ data at higher speeds than at slower paces. They went on to explain that the runners in the latter category were 800 or 1500 m specialists and spent more time training at higher velocities relative to what is spent at slow running speeds. It is possible that the Vm70 and the Vm50 group did not differ in economy at 2.68



$\text{m}\cdot\text{s}^{-1}$ because this velocity is much too slow to be a training speed. The trained runners, some of whom were middle distance runners, habitually train at much higher velocities.

In the present study, economy was also measured at a velocity that would elicit an effort near the individual ventilatory threshold. This was done to attempt to examine relative economy measures closer to the velocities more commonly used by the trained runners. No significant group differences were elucidated when economy was expressed in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$. This could be due in part to the testing velocity utilized. It may have not been close enough to the trained runners' actual race pace. The average intensity for the Vm70 group during this economy test was only 76% of $\dot{V}\text{O}_{2\text{max}}$. Most elite marathoners and especially middle distance runners race at higher relative intensities [11].

Bergh *et al.* [3] explored the relationship between body mass and oxygen uptake. They clearly indicated that linear scaling did not adequately adjust for body mass as the oxygen demand of running did not increase proportionally to body mass. This would effectively lead to lighter people requiring a seemingly higher oxygen uptake per kg of body mass than heavier people when expressed as $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. It would seem valuable to express the submaximal oxygen uptake during running as $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$ in order to rule out the effects of unequal body mass. Bergh *et al.* [3] found that instead of an exponent of 1.0, exponents may actually vary between about 0.67 and 0.75. When the RE data in this study were adjusted so the mass was scaled to an exponent of 0.75, there were still no statistically significant group differences found in $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$ or in $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{km}^{-1}$. Scaling mass to an exponent of 0.67 was also attempted with no significant differences evident between groups. Few studies have examined the acute affects of prolonged exercise on running economy [18,27,31]. Data, from the current investigation, suggest that prolonged running near the ventilatory threshold (average run time of 43.7 ± 10.9 min at 84% $\dot{V}\text{O}_{2\text{max}}$ for Vm50 and 60 min at 76% $\dot{V}\text{O}_{2\text{max}}$ for Vm70) did not have an effect on the RE of either group. Sproule [27] also attempted to discover the effects of prolonged running on RE using three different run intensities: 40 min at 80% $\dot{V}\text{O}_{2\text{max}}$, 60 min at 70% $\dot{V}\text{O}_{2\text{max}}$, and 60 min at 80% $\dot{V}\text{O}_{2\text{max}}$. Sproule's [27] subjects were similar in age (23 ± 2 yrs) and $\dot{V}\text{O}_{2\text{max}}$ (56.5 ± 4.6 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) compared to the Vm50 group of this study. They found that RE decreased significantly immediately following both 60 min runs. However, they found no statistically significant difference in RE following the 40 min run at 80% $\dot{V}\text{O}_{2\text{max}}$. It was concluded that these results supported the hypothesis that RE deteriorates during prolonged running and that the magnitude of the deterioration in RE increases with both increasing exercise intensity and duration. The results



from the 40 min run at 80% $\dot{V}O_{2max}$ were similar to the Vm50 group as they ran for an average of 43.7 ± 10.9 min at 84% $\dot{V}O_{2max}$ with both showing no effect on RE. In contrast to Sproule's [27] results, the Vm70 group in this study (who ran for 60 minutes at 76% $\dot{V}O_{2max}$) showed no statistically significant decreases in RE after a prolonged run. Also, in contrast to the present work, are the results from the following two studies. Xu and Montgomery [31] found that both a 90-min run at 65% and 80% $\dot{V}O_{2max}$ decreased RE. The magnitude of the increase in submaximal oxygen consumption following the prolonged run was greater for the 80% $\dot{V}O_{2max}$ intensity. Kyrolainen *et al.* [18] demonstrated that after a marathon, a standardized 5-min submaximal running test, resulted in a significant increase in oxygen consumption, ventilation, and heart rate. While Dressendorfer [14] tested RE following a 21.1 km run (mean race time 89.5 min) at race pace (3.98 ± 0.55 m·s⁻¹, equivalent to 74-80% $\dot{V}O_{2max}$) and no significant increase in $\dot{V}O_2$ was evident.

Morgan *et al.* [22], investigated RE 1 to 4 days post run and had similar findings to the present study. These authors attempted to document the effects of a 30 min maximal run (89% $\dot{V}O_{2max}$) on running economy. No significant difference in RE up to four days following the prolonged maximal run was reported. Zavorsky *et al.* [32] examined the effects of intense interval workouts on RE and found that RE decreased after the high-intensity workout. Changes in $\dot{V}O_2$, HR and RER were observed and were found to be independent of the recovery duration between the repetitions.

In the present study there was a statistically significant decrease in RER during the RE test at 2.68 m·s⁻¹ following the prolonged run for both groups. This is consistent with most studies that have reported a decrease in RER following prolonged running. It has been attributed to an increased reliance on fat as an energy source [14,22]. Since carbohydrates are a more efficient fuel (less oxygen per gram) for energy production [5], it has been suggested that an increased dependency on fat combustion could be partly responsible for a rise in submaximal $\dot{V}O_2$ following prolonged work [1]. Since a lower RER was found after the prolonged run, it would seem reasonable to assume that fewer carbohydrates were available to be used as a source of energy. However, it would seem that this increased reliance on fat and subsequent decrease in RER was insufficient to significantly affect the oxygen consumption of the subjects in this investigation.

It has been suggested that the increase in oxygen cost during prolonged exercise may be attributed to several mechanisms. These include the following: (1) an increase in HR to compensate for a decrease in stroke volume, (2) an increase in core temperature as a results of thermal stress, (3) an increase in blood catecholamine levels, (4) a shift in substrate utilization to an increase in fat



metabolism resulting from decreases in muscle and liver glycogen stores, (5) a decrease in biomechanical efficiency [1,17,19,24,31].

Heart rate values increased during the prolonged run from a mean of 150 to 170 bpm in the Vm70 group and from 165 to 180 bpm in the Vm50 group. The gradual increase in HR, observed during a constant velocity prolonged run, is evidence of a circulatory change. It may be attributed in part to a fall in central blood volume which causes a decreased filling pressure, and results in a decreased stroke volume [25]. Another more recent explanation for stroke volume decline during exercise has been offered by Fritzsche [16]. In a thermoneutral environment, a stroke volume decline during prolonged exercise relates to increased exercise heart rate and not increased cutaneous blood flow. They stated that more than likely the progressive increase in heart rate, with cardiovascular drift during exercise, decreases end-diastolic volume, subsequently decreasing stroke volume. The decreased stroke volume, coupled with a possible withdrawal of parasympathetic tone [17], should describe the increases in HR observed during the prolonged run. Despite the observed increase in HR during the prolonged run, there was no significant difference in HR values between pre and post RE tests for either group. During the prolonged runs subjects were encouraged to ingest water. The weight loss observed as a result of the prolonged run was 1.6% of body weight for the Vm70 group and 0.7% for the Vm50 group. Even small amounts of dehydration (1-4.2 % reduction in body weight) can lead to an increase in core body temperature [20], and negatively influence endurance performance [12]. An increase in core temperature directly affects metabolic rate through the Q_{10} effect [19]. An increase in core temperature can also induce an increase in \dot{V}_E , and this in turn should increase the metabolic cost for the respiratory muscles and thus increase $\dot{V}O_2$ [1]. In the present study, there were no observed increases in \dot{V}_E and coupled with the relatively low weight loss, the possibly increased core temperature seemed to have had no significant effects on RE.

Despite the observed decrease in RER and the reduction of body weight no statistically significant difference in RE was found immediately following the prolonged run. Perhaps the prolonged run for the Vm50 group was of insufficient duration (44 min average), and that of the Vm70 group was of insufficient intensity to cause an increase in their respective economy values. It would seem that RE is a stable measure not easily perturbed by prolonged work of less than 60 minutes at intensities less than 80% of $\dot{V}O_{2max}$. This study seems to demonstrate that for both trained and untrained individuals there may be a critical workload that must be maintained in order to cause decreases in a runner's economy.



In conclusion, this study demonstrated that there were no differences between groups in RE for both relative and absolute measures of economy. Even when the RE was expressed as $\text{ml}\cdot\text{kg}^{-0.75}\cdot\text{min}^{-1}$, in order to rule out the effects of the significantly different mean body mass of the two groups, there were still no significant differences evident. Improved RE may only occur at the velocities at which an athlete trains. At unfamiliar running velocities, RE appears to vary significantly between individuals for both highly trained and untrained individuals. This variation in RE tends to mask the differences, if any, found between groups differing significantly in training status. Following a prolonged run for up to 60 minutes at an intensity near the subject's individual ventilatory threshold, RE was not perturbed from previously recorded values in both groups. This study demonstrated that RE is a fairly stable value that is not easily disturbed by exercise at intensities near the ventilatory threshold for 60 minutes or less, regardless of training status.

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