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Running economy of elite male and elite female runners

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ABSTRACT

DANIELS, J. and N. DANIELS. Running economy of elite male and elite female runners. *Med. Sci. Sports Exerc.* Vol. 24, No. 4, pp. 483–489, 1992. Twenty female and 45 male middle and long-distance runners, in training for the U.S. Olympic Trials, served as subjects. Ninety percent of both men and women subjects reached the Trials; eight women and 12 men qualified for the Olympic Games and five won medals. Each subject completed a $\dot{V}O_{2max}$ and a series of submax treadmill runs, for the purpose of comparing heart rate (HR), $\dot{V}O_2$, and blood lactate (HLa) among men and women and among runners of various event specialties. Results showed the men to be taller, heavier, to have a lower six-site skinfold sum and a higher $\dot{V}O_{2max}$, than the women ($P < 0.05$); there was no difference in age. When compared in running economy, men used less oxygen ($ml \cdot min^{-1} \cdot kg^{-1}$) at common absolute velocities, but $\dot{V}O_2$ ($ml \cdot km^{-1} \cdot kg^{-1}$) was not different between men and women at equal relative intensities (%$\dot{V}O_{2max}$). When men and women of equal $\dot{V}O_{2max}$ were compared, the men were significantly more economical, using any method of comparison. Also, when comparisons of men and women of equal economy were made, it was found that the men had an even greater advantage over the "matched" women subjects than the mean $\dot{V}O_{2max}$ comparison using all subjects. In looking at the SD (800-/1500-m runners), MD (3-K/5-K/10-K runners) and LD (marathon runners), it was found that the SD runners used the least oxygen ($ml \cdot min^{-1} \cdot kg^{-1}$) at speeds of marathon race pace and faster, but not at slower speeds. Men and women responded similarly in this regard. Running economy data for speeds slower than typical race paces, tended to show the LD runners to be most economical, suggesting that the speeds over which runners are tested plays an important part in determining which subjects are the most economical. It was concluded that at absolute running velocities, men are more economical than women, but when expressed in $ml \cdot km^{-1} \cdot kg^{-1}$ there are no gender differences at similar relative intensities of running. Also, when men and women of equal $\dot{V}O_{2max}$ or equal economy are matched, the men show a better aerobic profile. It is recommended that economy data be collected up to speeds equal to over 90% $\dot{V}O_{2max}$.

RUNNING ECONOMY, $\dot{V}O_{2SUBMAX}$, ECONOMY OF EXERCISE, ELITE RUNNERS, ELITE ATHLETES, OXYGEN CONSUMPTION

Although the aerobic demands of submaximal running have been investigated for many years, $\dot{V}O_{2max}$ has generally been the factor that has received most attention relative to identifying talented endurance athletes. Among a heterogeneous group of runners, $\dot{V}O_{2max}$ does, indeed, correlate highly with distance-running performance. However, when a homogeneous group of runners is studied, $\dot{V}O_{2max}$ becomes poorly correlated with, and running economy, highly correlated with performance. Running economy is defined as the relationship between oxygen consumption ($\dot{V}O_2$) and velocity (v) of running, or as the aerobic demands of running.

The number of factors that affect running economy are many; indeed, age (11), training (5), stride rate and frequency (17), shoe weight (15), wind (13,20) and air resistance, including the lower density found at altitude (8,13), have all been shown to affect the $\dot{V}O_2$ related to submaximal running intensities. Furthermore, clothing, footing, terrain, and possibly fatigue are additional factors that can change the "cost" of running.

The differences in running economy that may exist between males and females has also been investigated, but with mixed findings. Some investigators have reported no difference in running economy, based on gender (10,14,16,18); others have found males to be more economical (1,2). Often, comparisons have been made with untrained or unequally trained subjects, or between different studies involving only male or only female runners. In addition, speeds utilized in most studies have been slower than typical race pace for the individuals involved. The present study was designed to evaluate running economy over a range of submax velocities, among elite female and elite male middle- and long-distance runners.

METHODS AND PROCEDURES

Subjects. Male and female runners, sponsored by NIKE, Inc. Shoe Company, volunteered to be subjects. Twelve of the 20 female subjects and 36 of the 45 male subjects were members of Athletics West (AW), NIKE's elite-athlete track club, which was housed in Eugene, OR. The remaining 17 subjects were either Americans ($N = 5$) training in Eugene or NIKE-sponsored foreign runners who were visiting Eugene prior to the 1984 Olympic Games. Eighteen of the 20 women and 41 of

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the 45 men qualified for the Olympic Trials. Eight women and twelve men reached the Olympic Games; two women and three men won medals.

AW athletes were all tested on more than one occasion, between 1983 and 1986; non-AW runners were tested one or more times during the same period. When more than one set of data were available for any athlete, the mean of all tests was used to represent that subject.

Economy and $\dot{V}O_{2max}$ tests. Each test session included a series of submax, level-grade treadmill runs, followed by a constant-speed, increasing-grade treadmill run, to determine $\dot{V}O_{2max}$. Submax test velocities used were 248 $m \cdot min^{-1}$ (starting speed for most female subjects), 268 $m \cdot min^{-1}$ (initial speed for all men and some women), 290, 310, 330, and 350 $m \cdot min^{-1}$. Some men also ran 370, even 390 $m \cdot min^{-1}$.

For the submax tests, the treadmill was set at the desired speed, then, once the subject was running, 10 revolutions of the treadmill belt were timed and any necessary adjustments made during the first 30 s of each test. If the pace was not exactly as planned (it was always within 2 $m \cdot min^{-1}$), the actual velocity was recorded for the test being run. Each submax test lasted 6 min, with expired-air samples collected in meteorological balloons during the final 2 min of each run. Low-resistance breathing valve and collection valve were used in all tests. Heart rates, palpated the first 10 s after each run, and post-run lactates taken 30 s after the completion of each run were also recorded for each subject. A blood-lactate accumulation of 4.0 $mmol \cdot l^{-1}$ was used to terminate the submax series of runs. There was a 5-min recovery period between submax tests. All female subjects reached 310 $m \cdot min^{-1}$ (many reached 330); all males ran at least 330 $m \cdot min^{-1}$, and most did 350 $m \cdot min^{-1}$ before achieving a blood lactate concentration of 4.0 $mmol \cdot l^{-1}$.

Five to 10 min following the final submax run, a $\dot{V}O_{2max}$ test was performed, using each subject's final submax treadmill velocity (but not faster than 350 $m \cdot min^{-1}$) as the test speed for the max test. The first 2 min of each max test were at 0% grade; 1% grade was added to the treadmill each subsequent minute starting with minute 3. The test was terminated when the subject decided he/she could not complete another minute. Consecutive, 30-s bags were collected, starting at the 3.5-min point in each test, and continued until the test ended, which was usually 6–7 min, total test time. The highest $\dot{V}O_2$ recorded was accepted as $\dot{V}O_{2max}$.

Gas volumes were measured with a Collins 350-l gasometer; expired fractions of CO_2 and O_2 were determined by a Lloyd-Gallenkamp volumetric gas analyzer. Blood lactates were measured with a YSI Blood Lactate Analyzer, using a 25-μl sample taken from a separate finger stick following each test.

RESULTS

General characteristics of the subjects are presented in Table 1. There was no difference between the males and females in age or in maximum heart rate; the men were taller, heavier, had a lower six-site skinfold sum and a higher $\dot{V}O_{2max}$, than did the women.

Table 2 shows the mean data for the females, broken down into three categories—800-/1500-m specialists, 3000-m/5000-m/10-km runners and marathon runners. The marathoners were older, but not significantly so ($P > 0.05$); the mean age of this group was greater mainly due to one of the subjects being in her late 30s at the time of testing. The 800/1500 runners had a significantly lower $\dot{V}O_{2max}$, both when expressed in absolute terms ($l \cdot min^{-1}$) and in relative terms ($ml \cdot min^{-1} \cdot kg^{-1}$), as shown in Table 2. Table 3 presents the same data for men as shown in Table 2 for women. As with the females, no differences existed among the male event groups in age, height or skinfold thickness ($P > 0.05$). However, the 800-/1500-m specialists were heavier than either of the other groups, and the 3-km/5-km/10-km runners had a higher $\dot{V}O_{2max}$ in $ml \cdot min^{-1} \cdot kg^{-1}$ than did the 800-/1500-m runners. It should be pointed out that the 800-/1500-m men had the highest $\dot{V}O_{2max}$, expressed in $l \cdot min^{-1}$, but because of their greater body weight, did not have a $\dot{V}O_{2max}$ advantage, expressed in relative terms.

Running economy. By plotting VO_2 data against running velocity, "economy curves" were generated for each subject. These resulting individual regression equations were then used to generate $\dot{V}O_2$ values for the exact common speeds strived for in the submax tests—248, 268, 290, 310, 330, and 350 $m \cdot min^{-1}$. The economy curves, $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$ (velocity related to $\dot{V}O_{2max}$), for both men and women, are depicted in Figure 1. At the three common test velocities (268, 290, and 310 $m \cdot min^{-1}$), the male runners were more economical (consumed less oxygen) than their female

TABLE 1. Characteristics of elite runners.

		Age (yr)	Height (cm)	Weight (kg)	SF[a] (mm)	$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	HR_{max} ($b \cdot min^{-1}$)
Female	20	26.7	166	52.2	47.3	66.2	195
Male	45	27.0	180[b]	65.4[b]	35.4[b]	75.4[b]	194

[a] Six-site sum.
[b] Different from females, $P < 0.05$.

TABLE 2. Characteristics of elite female runners.

Group		Age (yr)	Height (cm)	Weight (kg)	SF[a] (mm)	$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)
800-/1500-m	8	25.5	166	51.8	48.1	63.1[b]
3K/5K/10K	5	26.2	165	51.3	45.5	68.4
Marathon	7	28.4	167	53.2	47.6	68.1

[a] Six-site sum.
[b] $P < 0.05$.

counterparts ($P < 0.05$). The combination of a higher $\dot{V}O_{2max}$ (Table 1 and Fig. 1) and better economy (Table 1) also resulted in a significantly higher $v\dot{V}O_{2max}$ (381 vs 332 $m \cdot min^{-1}$) for the men ($P < 0.05$). The $v\dot{V}O_{2max}$ difference is 14%, suggesting that the men have a 14% advantage in aerobic capabilities ($\dot{V}O_{2max}$ and economy, combined).

If the men and women are compared at *relative* intensities of effort (common percentages of $\dot{V}O_{2max}$, including $v\dot{V}O_{2max}$), rather than at absolute velocities of running, then the differences in economy are only 1–2%, which is not significant ($P > 0.05$). This, relative-intensity comparison, expressed in $ml \cdot kg^{-1} \cdot km^{-1}$, is presented in Figure 2 and only favored the men at 70% $\dot{V}O_{2max}$ and slower, which is below race intensity, even for marathon runners.

Additional evidence that the women were equal to the men in running economy, when expressed in terms of relative intensity of effort, was found in the results of the blood lactate data. A lactate concentration of 4.0 $mmol \cdot l^{-1}$ corresponded to a $\dot{V}O_2$ representing 87.1% of $\dot{V}O_{2max}$ for the women and 85.5% of $\dot{V}O_{2max}$ for the men ($P > 0.05$). Also, at a 4.0 $mmol \cdot l^{-1}$ blood lactate accumulation, the women were at 90.8% of HR_{max}, the men at 89.3% of their HR_{max}; again, no significant difference existed ($P > 0.05$). At any common, absolute running velocity, the women were always at a higher HR and higher blood lactate concentration than were the men, just as they were at a higher $\dot{V}O_2$, as shown in Figure 1.

TABLE 3. Characteristics of elite male runners.

Group		Age (yr)	Height (cm)	Weight (kg)	SF[a] (mm)	$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)
800-/1500-m	13	26.6	182	69.0[b]	35.6	72.5
3K/5K/10K	23	26.6	178	63.4	35.3	77.4[c]
Marathon	9	28.6	181	65.3	35.4	74.4

[a] Six-site sum.
[b] $P < 0.05$ relative to other groups.
[c] $P < 0.05$ relative to shorter distances.

DISCUSSION

The characteristics of the present subjects are similar to those reported for elite runners in other studies (7,12,19). The single highest $\dot{V}O_{2max}$, for women (78.6 $ml \cdot min^{-1} \cdot kg^{-1}$) has been reported earlier (12), and was that of an Olympic Gold Medalist in the marathon. For the men, the highest $\dot{V}O_{2max}$ was 81.0, reached by a non-Olympian. The highest $\dot{V}O_{2max}$ of an Olympian, from the present group of male subjects, was 79.3; of the Olympic Medalists, the highest $\dot{V}O_{2max}$ was 72.1 $ml \cdot min^{-1} \cdot kg$. This medalist, and another of the male subjects, who was a Gold Medalist, were both 800-m specialists, an event which is as highly anaerobic in nature as it is aerobic, and a high $\dot{V}O_{2max}$ is obviously not a necessity. Both the male and female 800-/1500-m specialists in the current study were lower in $\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$) than were the longer-distance specialists (Tables 2 and 3), but the 800-/1500-m men were also the largest and had a 5.0 $l \cdot min^{-1}$ absolute $\dot{V}O_{2max}$.

The six-site skinfold sums are particularly low; the low and high values for men were 24.9 and 48.6 mm. The extremes for women were 36.4 and 59.7 mm. Previously reported sums for the same six sites for females averaged 54.9 mm (12). For elite males, the 35.4 mm sum is comparable to the seven-site values reported by Pollock (19) in 1977. Rather than attempt to convert the skinfold data to a representative percentage of body fat, it is these investigators' opinion that the raw skinfold data are more useful among elite runners. In fact, a simple two-site sum (umbilical plus

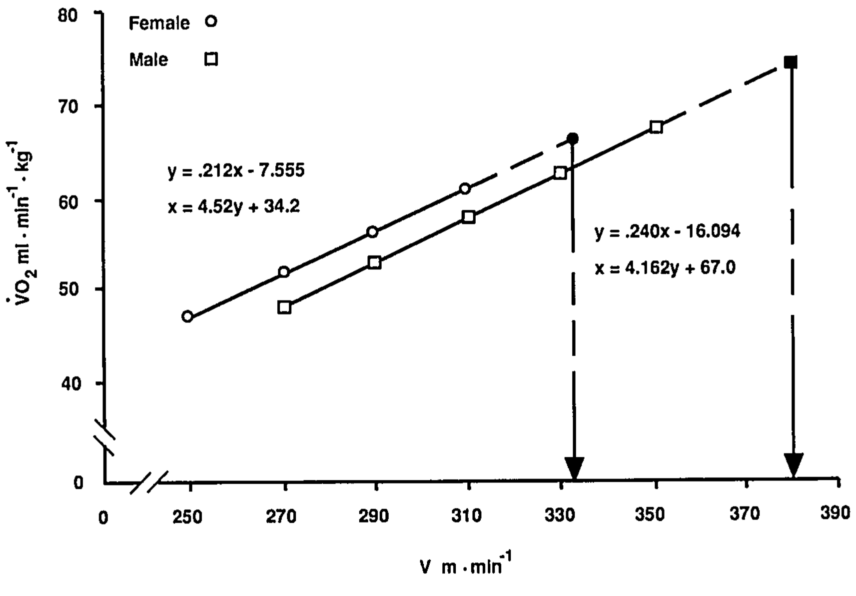

Figure 1—Aerobic profiles of elite female (N = 20) and elite male (N = 45) runners. Significant differences favor the males in $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, and running economy at all common absolute running velocities ($P < 0.05$).

anterior thigh, which are both easy to obtain on both females and males) has proved to be very useful with elite runners and correlates well with the six-site sums (R = 0.80 for women, 0.91 for men). For the two-site sum referred to, elite male runners typically fall between 10 and 15 mm (equal to 30.6 to 40.5 six-site sum) and the elite females, between 15 and 20 mm (42.7 to 52.3 six-site sum). The two-site means for the men and women elite runners tested were 12.4 and 17.1 mm, respectively.

The mid- to upper-20s average age of the subjects is not surprising since membership in Athletics West is restricted to athletes who do not have any remaining collegiate eligibility. Also, the fact that there has become greater financial support for runners, beyond their collegiate days, leads to more athletes remaining active in sport. The age of the current male subjects was not greater than reported by Pollock in 1977 (19), but was significantly older than in Daniels' study of elite males in 1968 (7). Also, the age of the current females was greater than reported by Daniels et al. (12) in 1984, for an equally impressive group of elite female distance runners.

The running economy data, shown in Figure 1, agree with some previous investigators (1,2) that males are more economical than females when compared at common running velocities. Certainly, economy is an important factor in distance-running performance, and even though the males have a much greater advantage in $\dot{V}O_{2max}$ (Table 1), than in economy (Fig. 1, which shows a 6–7% economy advantage for the males), economy can and does often determine the difference in performance between individuals with equal or near equal $\dot{V}O_{2max}$, as shown earlier by Conley and Krahenbuhl (4). An example of two of the current subjects dramatizes this quite well. One of the current male subjects holds the American record in a long-distance event; one of the females, the American record for women in the same event. Their respective $\dot{V}O_{2max}$ values are 78.7 and 78.6 $ml \cdot min^{-1} \cdot kg^{-1}$. Based on the male's economy curve, and if he were to race his event at 83.7% of his $\dot{V}O_{2max}$, as determined by Daniels and Gilbert (9), his time would be within a few seconds of his record. The comparable female record holder, based on her economy and an intensity of 83.1% $\dot{V}O_{2max}$ (9), would run a marathon within a few seconds of her record, and more than 12 *minutes* slower than would the man, who has no $\dot{V}O_{2max}$ advantage at all. Differences in economy can clearly explain differences in performance when $\dot{V}O_{2max}$ data are equal, as can they explain equal performances among individuals of vastly different $\dot{V}O_{2maxes}$. Two of the current female subjects (subject A and subject B) have 10-km bests within 20 s of each other; both are among the best in the world. Their respective $\dot{V}O_{2maxes}$ are 66.4 and 71.2, both well below the value displayed by the marathoner referred to above, whose 10-km time is also quite comparable to subjects A and B. Actually, the fastest 10-km time is held by subject A, who is also an Olympic Silver Medalist in the marathon. In examining the economy data of these two athletes, and if both were to race a 10-km in 32:00, A would be at 95.4% of her $\dot{V}O_{2max}$, B would be at 96.5% of her $\dot{V}O_{2max}$. Clearly, at an equal intensity of effort, A should win, as she has on many occasions.

The reference to *relative intensity* is an important one, because it is the authors' belief that well-trained runners all perform at near-equal percentages of their respective $\dot{V}O_{2maxes}$ for various durations of time, as described by Daniels and Gilbert earlier (9). In support of this contention, is the fact that eight of the subjects in the current study, all of whom raced marathons within a few weeks of being tested, performed at an average of 84.6% of $\dot{V}O_{2max}$, with six of the eight between 84.0 and 84.9% of $\dot{V}O_{2max}$ (the other two were at a calculated 82.8 and 88.2% $\dot{V}O_{2max}$).

Because of the importance of relative intensity, the current males and females were compared in economy at equal percentages of their respective $\dot{V}O_{2max}$. Units of measure used for this comparison was $ml \cdot kg^{-1} \cdot km^{-1}$, since running velocities were not the same. Figure 2 presents these findings and shows that none of the intensities typically used in races up through the marathon, produced significant differences between the males and females in running economy ($P > 0.05$). Figure 2 also suggests that the aerobic demand, and energy demand, of running is not necessarily independent of speed as has been earlier suggested (3). However, from among the current pool of 65 subjects, there were 16 who showed equal aerobic demands over all speeds tested and six who had lower $\dot{V}O_2$ data at higher speeds than at slower paces. Those who fit into the latter category, and most of the subjects in both of these two categories were 800-/1500-m specialists, who spend a great deal of time training at higher velocities relative to what is spent at slow running speeds. So, it is certainly

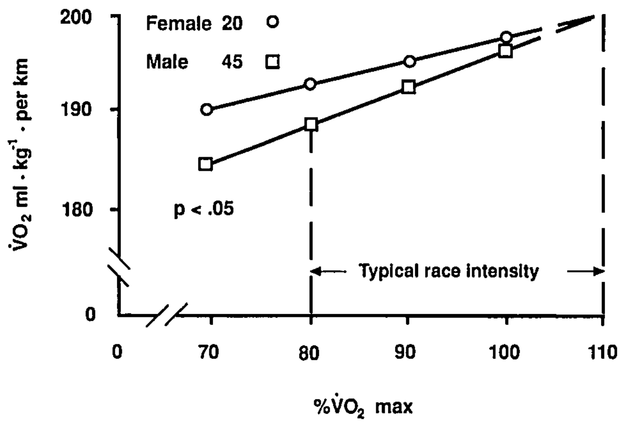

Figure 2—Aerobic demands of running (per kilometer) for elite female and elite male runners. No differences exist ($P > 0.05$) within the range of most race intensities (80–110% $\dot{V}O_{2max}$).

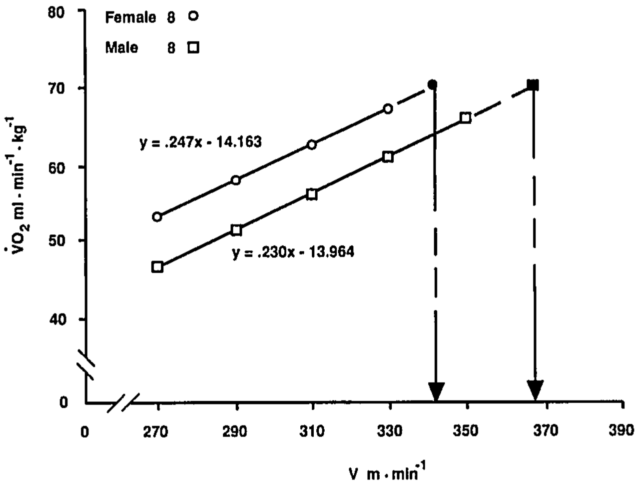

Figure 3—Comparison of male and female runners of equal $\dot{V}O_{2max}$. The males are significantly favored in economy and in $v\dot{V}O_{2max}$ ($P <$ 0.05).

possible to collect data either supporting or refuting the claim that the "cost" of running is independent of speed, depending upon the type of subjects tested.

In an attempt to clarify the relationship between $\dot{V}O_{2max}$ and running economy, and why the average male is faster than the average female runner, eight women who had the highest $\dot{V}O_{2max}$ were closely matched with eight male runners of equal $\dot{V}O_{2max}$. The running economies for these $\dot{V}O_{2max}$-matched subjects are presented in Figure 3. It appears that the women with the highest $\dot{V}O_{2max}$ have economies that are not as good as the overall average for women, as presented in Figure 1. It also appears that the "matched" males are better than the average of all males in economy, and worse than average in $\dot{V}O_{2max}$, by design. The resulting $v\dot{V}O_{2max}$ data, shown in Figure 3, give the males a 7–8% performance advantage were both to run at $\dot{V}O_{2max}$.

Figure 4 takes the male/female comparison a step farther. In this case, the eight most economical female runners were matched with eight males of equal running economy, at comparable absolute running velocities. The result gives the males a 14% $\dot{V}O_{2max}$ advantage and a 14% $v\dot{V}O_{2max}$ advantage. One thing seems quite clear—elite male runners have a decided aerobic advantage over elite female runners; they have a better aerobic profile.

Velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) appears to be a more desirable predictor of running success than $\dot{V}O_{2max}$ or economy, alone, since $v\dot{V}O_{2max}$ gives some insight as to how fast an individual can run when operating at $\dot{V}O_{2max}$ or at any fraction of that $\dot{V}O_{2max}$. As shown in Figure 1, $\dot{V}O_{2max}$, and economy, are each only part of the performance difference between males and females. Also, as shown in Figures 3 and 4, having equal $\dot{V}O_{2max}$ or equal economy does not guarantee equal performance, even in a purely aerobic sense.

One danger of comparing runners based on economy measures from submax tests is that the test speeds are not fast enough to reflect race intensities. $\dot{V}O_2$ at 268 $m \cdot min^{-1}$ (6:00 per mile pace) is a typical test intensity, often because a heterogeneous group of subjects can all attain this speed within their aerobic capacities, often because a treadmill is not capable of faster speeds. When possible, submax data should be collected to an intensity which represents 95% of each individual's $\dot{V}O_{2max}$. If final test speeds prove to be too close to $\dot{V}O_{2max}$, producing a flattening of the economy curve, then the final speed should be discarded; however, higher speeds should be attempted. A 95% $\dot{V}O_{2max}$ effort allows the athlete to reach 10-km race pace and usually

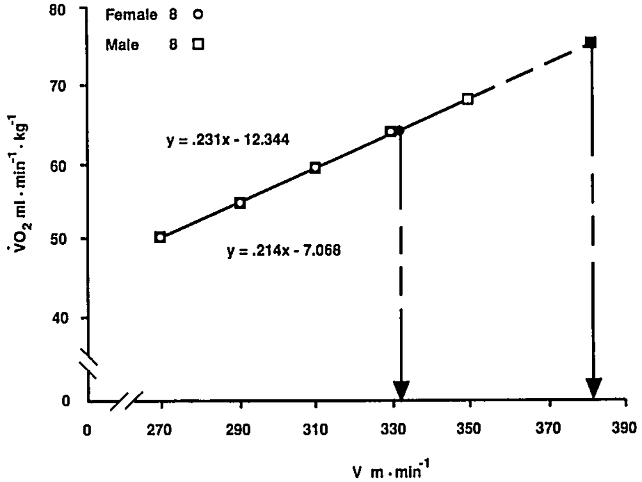

Figure 4—Comparison of male and female runners of equal running economy, over common test velocities. Males are favored in $\dot{V}O_{2max}$ and in $v\dot{V}O_{2max}$ ($P < 0.05$).

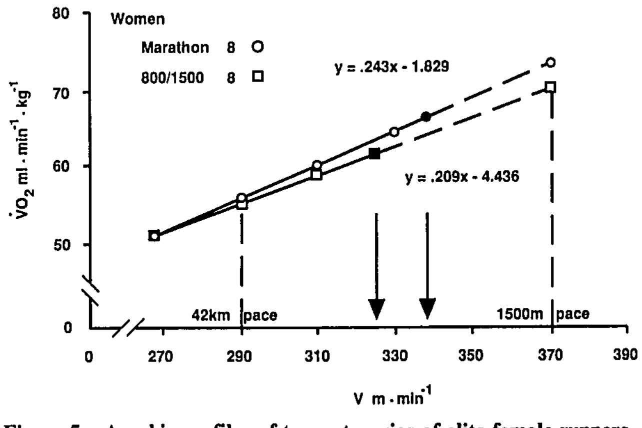

Figure 5—Aerobic profiles of two categories of elite female runners. Significant differences favor the marathon runners in $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$, but favor the 800-/1500-m specialists in economy at 1500-m race pace, due to a flatter slope ($P < 0.05$) of their regression curve relating running velocity to $\dot{V}O_2$.

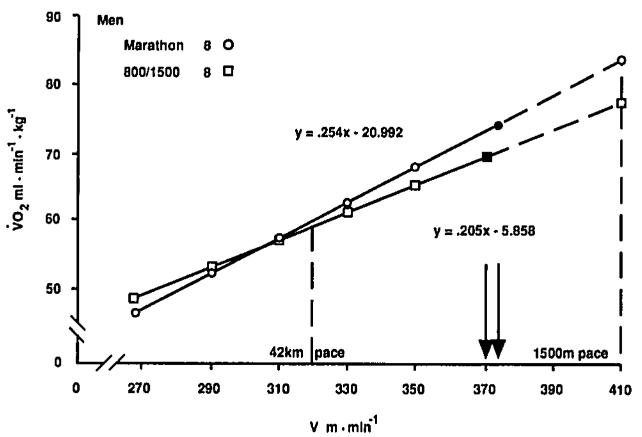

Figure 6—Aerobic profiles of elite male runners. Significant differences ($P < 0.05$) favor the marathon runners in $\dot{V}O_{2max}$, but favor the 800-/1500-m specialists in economy at 350 m•min^{-1} and faster, due to a flatter slope ($P < 0.05$) of their regression curve relating running velocity to $\dot{V}O_2$.

to exceed a 4.0 mmol·l^{-1} blood lactate accumulation, as referred to above.

Figures 5 and 6 demonstrate how having economy data to high intensities and projections to or even beyond $\dot{V}O_{2max}$ can give additional insight into differences that may or may not exist at race intensities. To generate Figures 5 and 6, the eight best 800-m runners (which included some 1500-m runners also) were compared with the eight best marathon runners (including some who also specialized in 10-km races). Among the women, there was no difference in economy at marathon race pace, although it appears that tests slower than 268 m·min^{-1} may have suggested an advantage for the longer-distance specialists, as has been suggested by others (6,19). In the case of the men, the marathon runners were more economical at 6:00 pace (268 m·min^{-1}), and presumably at all slower speeds, but by marathon race pace the two groups were equal. Projection of the economy curves to and beyond $\dot{V}O_{2max}$ (up to 1500-m race pace) shows that the shorter-distance specialists have a decided advantage in running economy ($P < 0.05$). It is very possible that the range of velocities over which runners are tested can determine whether it is concluded that one runner, or type of runner, has an economy advantage over another. In the case of Figures 5 and 6, when the slopes of the regression curves are compared (0.209 vs 0.243, for women and 0.205 vs 0.254 for men), a significant difference occurs between the shorter and longer distance runners ($P < 0.05$). However, at common test speeds, just about any conclusion can be reached relative to running economy comparisons.

CONCLUSION

Relative to elite male and elite female runners the following is concluded. 1) Males are more economical than are females at common velocities of running. 2) No difference exists in running economy between males and females at typical, relative (%$\dot{V}O_{2max}$) race intensities. 3) Among males and females of equal $\dot{V}O_{2max}$, males are more economical, both at common velocities and at common relative intensities of running. 4) Among males and females of equal running economy, males have a greater $\dot{V}O_{2max}$ and a greater v$\dot{V}O_{2max}$. 5) Marathon runners have a greater $\dot{V}O_{2max}$ than 800-/1500-m specialists. 6) Due to a flatter regression curve (relating $\dot{V}O_2$ and running velocity), 800-/1500-m specialists are more economical at 800-/1500-m race pace, but not at marathon race pace. 7) Males and females both run at the same intensity (approximately 86% $\dot{V}O_{2max}$) when at a blood lactate accumulation of 4.0 mmol·l^{-1}. 8) When runners are tested for comparative purposes, $\dot{V}O_{2submax}$ (economy) data, which should be collected at speeds ranging up to 95% $\dot{V}O_{2max}$, as well as $\dot{V}O_{2max}$ and v$\dot{V}O_{2max}$ data, present the clearest possible "aerobic profile" for each individual.

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