

# Superior fatigue resistance of elite black South African distance runners

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*Liberty Life Chair of Exercise and Sports Science and the Medical Research Council/University of Cape Town Bioenergetics of Exercise Research Unit, Department of Physiology, University of Cape Town Medical School, Observatory 7925, South Africa*

COETZER, PIETER, TIMOTHY D. NOAKES, BARRY SANDERS, MICHAEL I. LAMBERT, ANDREW N. BOSCH, TONI WIGGINS, AND STEVEN C. DENNIS. *Superior fatigue resistance of elite black South African distance runners*. J. Appl. Physiol. 75(4): 1822–1827, 1993.—Black athletes currently dominate long-distance running events in South Africa. In an attempt to explain an apparently superior running ability of black South African athletes at distances >3 km, we compared physiological measurements in the fastest 9 white and 11 black South African middle- to long-distance runners. Whereas both groups ran at a similar percentage of maximal  $\dot{V}O_{2\max}$  over 1.65–5 km, the  $\% \dot{V}O_{2\max}$  sustained by black athletes was greater than that of white athletes at distances >5 km ( $P < 0.001$ ). Although both groups had similar training volumes, black athletes reported that they completed more exercise at >80%  $\dot{V}O_{2\max}$  ( $36 \pm 18$  vs.  $14 \pm 7\%$ ;  $P < 0.005$ ). When corrections were made for the black athletes' smaller body mass, their superior ability to sustain a high  $\% \dot{V}O_{2\max}$  could not be explained by any differences in  $\dot{V}O_{2\max}$ , maximal ventilation, or submaximal running economy. Superior distance running performance of the black athletes was not due to a greater ( $\pm 50\%$ ) percentage of type I fibers but was associated with lower blood lactate concentrations during exercise. Time to fatigue during repetitive isometric muscle contractions was also longer in black runners ( $169 \pm 65$  vs.  $97 \pm 69$  s;  $P < 0.05$ ), but whether this observation explains the superior endurance or was due to the lower peak muscle strength ( $46.3 \pm 10.3$  vs.  $67.5 \pm 18.0$  Nm/l lean thigh volume;  $P < 0.01$ ) remains to be established.

maximal oxygen uptake; isokinetic muscle function; race; distance running

IN THE 1960 OLYMPIC GAMES MARATHON, the Ethiopian Abebe Bikila became the first black African distance runner to win an Olympic gold medal; Bikila won the gold medal again in 1964. Since then, Kenyan black African runners have become the dominant force in international distance running.

The success of Kenyan runners is shown by their performances at the annual World Cross-Country Championships and in the Olympic Games. At the 1988 World Cross-Country Championships, Kenyan runners filled 8 of the top 10 places and runners from neighboring Ethiopia filled the remaining two places. Kenyan runners have won the senior men's team title at the World Cross-Country Championships for the past 8 yr and the junior men's team title for the past 6 yr (21). At the 1988 Seoul Olympic Games, Kenyan runners won the 800-m, 1,500-

m, and 3,000-m steeplechases and the 5,000-m events. On the basis of population percentages, the probability of Kenyans winning these races by chance alone is reported to be 1 in 1.6 billion when the entire Kenyan population is considered (6). Yet the elite Kenyan runners come from tribes that comprise <20% of the total population (D. Koech, personal communication); hence, the probability of this occurring by chance is even less.

Although excluded until recently from both national and international competition, black South African runners have also shown the ability to produce world-class performances. At the end of 1991, the 1st-, 2nd-, 5th-, and 9th-fastest times over 21.1 km (half-marathon) had been run by black South Africans, who had also run the 11th-, 13th-, and 18th-fastest standard 42-km marathon times, including the fastest marathon time in the world in 1992. Another black South African ran the fastest 50 km of all time. In 1989, black South African runners ranked 1st-5th and 10th in the world for both 15- and 21-km times.

Despite comprising only 20% of the competitive distance runners in this country, black South Africans dominate all distances, usually filling  $\geq 90\%$  of the top finishing positions in races from 5 to 56 km. Black runners have achieved 42 of the 50 fastest 21.1-km and 34 of the 50 fastest 42-km marathon times in South Africa.

In contrast, white runners dominate the shorter middle-distance running events in this country. Thus, 42 of the 50 fastest 800-m and 41 of the 50 fastest 1,650-m (1-mile) times have been recorded by white South African runners.

At present, there have been few attempts to provide a physiological explanation for this national dominance of the longer-distance races by black South African runners (4). Accordingly, the aim of this study was to further examine the possible mechanism(s) underlying an apparently superior running performance of black South African runners in races >5 km.

## MATERIALS AND METHODS

To ensure that only the very best white and black South African athletes were included in these investigations, we studied only athletes who had achieved one or more of the following performances: 1 mile in less than 04:00, 3,000 m in less than 08:20, or 5,000 m in less than 14:00. Most of these performances were achieved at alti-

TABLE 1. *Running times over various distances of elite white and black South African runners*

	1.65 km	3 km	5 km	10 km	21.1 km
White runners					
Mean	3:56	7:57	13:55	29:38	67:19
SD	0:03	0:14	0:13	0:40	2:06
<i>n</i>	9	9	6	9	5
Black runners					
Mean	4:04	8:07	13:43	28:33*	62:39†
SD	0:08	0:15	0:11	0:34	2:01
<i>n</i>	5	11	11	11	11

Times are given in min:s; *n*, no. of runners. Significantly different between black and white runners. \*  $P < 0.005$ ; †  $P < 0.0001$ .

tude (1,800 m) in the highveld around Johannesburg, South Africa. In view of the total domination of events >5 km by black runners, it was possible to compare only elite black and white runners whose performances were similar over shorter (<5 km) distances but very different over longer (>5 km) distances (Table 1).

Eleven black and 9 white runners qualified for study on the basis of their personal best times achieved within the competitive season during which they were studied. Each signed an informed consent form, and all were training intensively and competing actively. The subjects were asked to reduce their training before the laboratory studies and to prepare physically and mentally as if they were to perform competitive races on the test days. The testing protocols described below were approved by the Research and Ethics Committee of the Faculty of Medicine of the University of Cape Town.

For these tests, the subjects came to the laboratory on two consecutive days. On the first day, body mass and stature were measured. Biceps, triceps, subscapular, suprailiac, midthigh, medial calf, and abdominal skinfold thicknesses were also determined (24). Muscle mass was predicted as described by Martin et al. (17). Lean thigh volume was calculated on the assumption that the thigh is a truncated cone (15). Somatotype was calculated as described by Heath and Carter (14).

A preheparinized Jelco catheter (Critikon, Tampa, FL) was then placed in the athlete's right forearm vein and connected to a closed three-way stopcock for the later sampling of blood for lactate measurements, as previously described (18, 22). The athlete first warmed up at 16 km/h for 4 min and then ran at 17 km/h for 4 min and at 21 km/h for 15 min on a Quinton treadmill (Tiernay Electrical, Seattle, WA). During the last 2 min of the 17-km/h run and throughout the 21-km/h run, steady-state  $\dot{V}O_2$  uptake ( $\dot{V}O_{2s}$ ), respiratory exchange ratio (RER), and minute ventilation volume ( $\dot{V}E$ ) were measured as described previously (22). For these measurements, the subjects wore a noseclip and inspired air from a Hans Rudolph 2700 (Vacumed, Ventura, CA) one-way valve connected to an inspired gas meter (Mijnhardt, Litton, Oaijk, The Netherlands). Expired air was passed through a 15-liter baffled mixing chamber and a condensation coil to Ametek N-22 M  $O_2$  and CD-3 A  $CO_2$  gas analyzers (Thermox Instruments, Pittsburgh, PA). Before every test, the gas meter was calibrated with a Hans Rudolph 5530 3-liter syringe, and the analyzers were set with air

and a 4%  $CO_2$ -16%  $O_2$ -80%  $N_2$  mixture. Instrument outputs were processed by an on-line IBM PC computer that calculated the average inspired ventilation,  $\dot{V}O_{2s}$ , and  $CO_2$  production over each minute with the use of conventional equations.

Venous blood samples for lactate measurements were taken during a 30-s pause between the 17- and 21-km/h runs and at 1-min intervals over the 5 min after the 21-km/h run.

On the second morning, the athletes' maximal  $\dot{V}O_{2max}$  ( $\dot{V}O_{2max}$ ) was measured in a progressive treadmill running test to exhaustion. In this exercise test, the starting treadmill velocity was 17 km/h and the rate of increase in speed was 0.5 km/h every 30 s, as described previously (22).

Because of technical problems in keeping cannulas patent during high-speed running, venous blood samples were not taken during the maximal exercise test. Blood samples were drawn only at 1-min intervals over the first 5 min after the test for measurements of peak blood lactate concentrations. Similarly, difficulties in recording adequate electrocardiographic traces in heavily sweating athletes running at very high speeds prevented the measurement of maximal heart rates.

While the athletes recovered from the  $\dot{V}O_{2max}$  tests, they were interviewed to obtain details of their training regimens. Each athlete's weekly training program was analyzed for the 8 wk before each important race. Particular attention was paid to daily distance run, running speed, total running time per day, hill training, sprinting, gymnasium training, and details of fartlek, interval, and other speedwork sessions.

With the help of a trained dietician, each subject then completed a food frequency questionnaire for an analysis of daily diet. Estimated intakes of carbohydrate, alcohol, fat, and protein were calculated in kilojoules with the Floro Diet Data (Durban).

After a 1- to 2-h rest, each athlete was placed on a chair built according to the specifications of Edwards et al. (10) and Bigland-Ritchie et al. (3). In that chair, the athlete sat with his arms folded, his back angled at 100°, his knees at 90° flexion, and his pelvis secured to the chair by an adjustable belt. Once the use of the hip flexors had been limited by securing the pelvis, a cuff was placed just above the malleoli of the right ankle and linked via a chain to a precalibrated strain gauge for the measurement of right quadriceps isometric contraction torque. The lever length, used to calculate torque, was the distance between the attachment of the chain to the cuff and the lateral epicondyle of the knee.

Outputs from the strain gauge were processed by a locally built data acquisition unit (Scientific Exercise Systems, Cape Town, South Africa) interfaced with an IBM-compatible personal computer, which displayed the results on the computer screen. First, subjects performed three 6-s maximal voluntary contractions for the measurement of peak isometric torque. The computer program then drew two horizontal lines on the screen: one represented the highest of the three developed peak torques, and the other represented 70% of the maximal torque. Subjects then performed a series of maximal voluntary contractions, each lasting 6 s and separated by 4-s rest intervals, until the maximal developed torque was

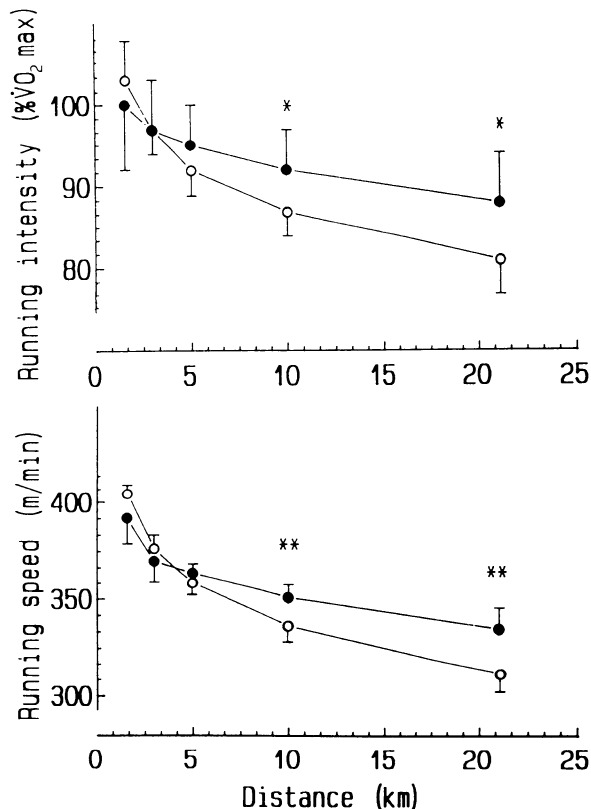


FIG. 1. Declines in running intensities and running speeds in elite black and white runners racing at increasing distances. Values are means  $\pm$  SD for 9 white (○) and 11 black male athletes (●). Running intensities and speeds over different distances were calculated from athletes' best race performances (Table 1), their  $\dot{V}O_2$  uptakes ( $\dot{V}O_2$ ) at different running speeds, and their maximal  $\dot{V}O_2$  ( $\dot{V}O_{2\max}$ ) measurements (Table 4). Significantly different between black and white runners: \* $P < 0.005$ ; \*\* $P < 0.0001$ .

<70% of the initial value (3, 27). Throughout this test, the athletes were verbally encouraged to produce maximal contractions for as long as possible, and the duration was recorded as the time to fatigue.

A muscle biopsy of the vastus lateralis was then taken under local anesthetic according to the method of Bergstrom et al. (2), as modified by Evans et al. (11), from the five white and six black runners who consented to the procedure. The biopsy sample was mounted in OTC compound embedding medium (Tissue Tek, Naperville, IL), frozen in pentane, cooled to  $-196^\circ\text{C}$  with liquid  $N_2$ , and stored at  $-80^\circ\text{C}$  for later analyses of percent fiber type by using the myosin adenosinetriphosphatase activity staining techniques of Dubowitz (9).

**Statistical methods.** Results from the groups of 11 black and 9 white runners are presented as means  $\pm$  SD. Differences between the groups were tested for statistical significance by an unpaired Student's *t* test using two-tailed *t* values for determinations of *P*. A *P* value of  $<0.05$  was regarded as statistically significant.

## RESULTS

Table 1 lists the running times over various distances of the athletes included in this study. Among the black athletes studied were four of the five all-time best performers over 10,000 m in South Africa, the South African

champions over 5,000 and 10,000 m, and the world's two fastest performers in the half-marathon (21.1 km) at that time. The white athletes included the South African champions for the 1,500-m, 1,650-m (1-mile), and 3,000-m races and the 3,000-m steeplechase.

The running intensities ( $\%\dot{V}O_{2\max}$ ), estimated from the  $\dot{V}O_{2\max}$  measurements (see below), and the running speeds sustained by the black and white athletes during their best performances (Table 1) over different distances are presented in Fig. 1. In making these calculations, we assumed that environmental influences on running times, including variations in the topography of the race courses and the prevailing wind and temperature conditions, were similar in the races in which the athletes achieved their best performances. Because all these athletes competed regularly at these distances, it is likely that the best performances of each athlete at the different distances were achieved under the most favorable racing conditions.

Whereas black and white athletes ran at similar  $\%\dot{V}O_{2\max}$  and running speeds over 1.65- to 5-km distances,  $\%\dot{V}O_{2\max}$  and running speeds sustained by the black athletes were significantly greater than those of the white athletes at distances  $>5$  km. In 21.1-km half-marathon races, black athletes ran at  $335 \pm 11$  m/min or  $20.1 \pm 0.7$  km/h and white athletes ran at  $312 \pm 10$  m/min or  $18.7 \pm 0.6$  km/h ( $P < 0.0001$ ).

There were also differences in the reported training intensities of the black and white runners (Fig. 2). Whereas the total training volumes of both groups were the same, the black runners reported that they completed a higher percentage of their total training volume at running intensities  $>80\%$  of  $\dot{V}O_{2\max}$  ( $35.6 \pm 17.7$  vs.  $13.5 \pm 7.1\%$ ;  $P < 0.005$ ).

Anthropometric measurements and skeletal muscle fiber composition of the black and white athletes are listed in Table 2. Black athletes were significantly shorter and lighter and had a considerably smaller muscle mass and estimated lean thigh volume than white athletes. The black athletes also had a lower sum of skin folds and hence probably less subcutaneous fat than white athletes. In contrast, there were no significant differences in percentage of type I slow-twitch fibers between black and white athletes.

There were also no major differences in the reported daily dietary intake of carbohydrates and fats between

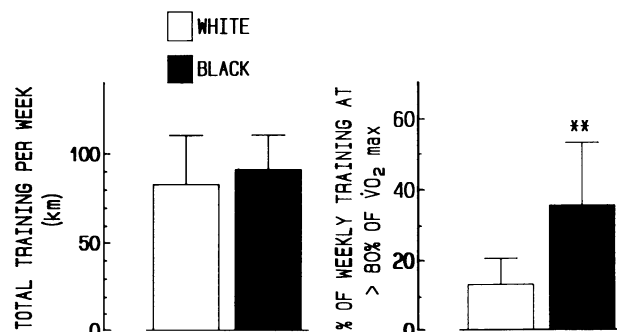


FIG. 2. Reported training volume and training intensity of elite black and white runners. Values are means  $\pm$  SD of 9 white and 11 black male athletes. \*\*Significantly different between black and white runners ( $P < 0.005$ ).

TABLE 2. *Anthropometric measurements in elite white and black South African athletes*

	White Athletes	Black Athletes	P
Height, cm	181.3±3.0	168.9±5.1	0.0006
Body mass, kg	69.9±5.6	56.0±5.4	0.0004
Endomorphy	1.7±0.5	1.4±0.3	NS
Mesomorphy	3.2±0.9	3.3±1.0	NS
Ectomorphy	3.9±0.6	3.9±1.1	NS
Muscle mass, kg	39.9±3.8	32.4±3.8	0.002
Sum of skinfolds, mm	43.9±8.6	34.8±5.0	0.012
Lean thigh volume, liters	4.2±0.5	3.5±0.4	0.0008
%Type I fibers	63.4±13.3	53.3±4.5	NS

Values are means ± SD for 9 white athletes and 11 black athletes, except for %type I fibers, where  $n = 5$  white runners and 6 black runners.

TABLE 3. *Analysis of dietary composition of elite white and black South African runners*

	White Athletes	Black Athletes	P
Daily energy intake, kcal/day	3,432±1,136	3,103±1,313	NS
Daily energy intake, kcal·kg <sup>-1</sup> ·day <sup>-1</sup>	49.5±18.0	62.2±15.0	NS
%Carbohydrate	50.9±5.7	55.7±8.0	NS
%Fat	31.1±5.8	29.8±5.7	NS
%Protein	18.1±2.1	14.5±3.1	0.008

Values are means ± SD for 9 white and 11 black athletes.

black and white runners (Table 3). Only the amount of protein ingested by the black runners was significantly less than that eaten by the white runners.

Measurements of  $\dot{V}O_2$  and blood lactate concentrations during maximal exercise and in submaximal runs at 17 and 21 km/h are reported in Table 4.  $\dot{V}O_{2\max}$  (l/min) was significantly lower in black than in white runners, but this difference disappeared when  $\dot{V}O_{2\max}$  was expressed relative to body mass. Similarly, the lower maximal  $\dot{V}E$  (l/min) of the black athletes also appeared to be a function of their smaller size and hence lower  $CO_2$  production. Running economy, defined as  $\dot{V}O_2$  at a running speed common to both groups (Table 4), and peak treadmill running velocity were also not different between black and white athletes, but peak and post-21-km/h running blood lactate concentrations and peak RER were significantly lower in the black runners than in the white runners. When the blood lactate concentrations in Table 4 were plotted against absolute (l/min)  $\dot{V}O_2$  values, the accumulation of blood lactate was found to be greater in the black athletes than in the white athletes at any given  $\dot{V}O_2$  (Fig. 3).

Differences between black and white runners were also found in the measurements of right quadriceps isometric contraction fatigue (Fig. 4). Irrespective of whether the torque values were expressed in absolute terms or corrected for differences in estimated lean thigh volume, the pattern was the same. Compared with the white athletes, the black athletes developed lower peak torques ( $67.5 \pm 18.0$  vs.  $46.3 \pm 10.3$  Nm/l;  $P < 0.01$ ) and fatigued less rapidly ( $97 \pm 69$  vs.  $169 \pm 65$  s;  $P < 0.05$ ). The areas under the fatigue curves of the black and white athletes were both  $\sim 100$  Nm·l<sup>-1</sup>·min, and in each group there

TABLE 4. *Lactate and respiratory measurements in elite white and black South African distance runners during submaximal and maximal treadmill exercise*

	White Athletes	Black Athletes	P
At 17 km/h			
$\dot{V}CO_2$ , l/min	3.3±0.4	2.7±0.1	<0.005
$\dot{V}O_2$ , l/min	3.5±0.3	2.9±0.2	<0.0001
$\dot{V}O_2$ , ml·min <sup>-1</sup> ·kg <sup>-1</sup>	50.7±2.7	51.3±3.9	NS
$\dot{V}E$ , l/min	69.6±11.1	65.0±7.8	NS
$\dot{V}E$ , l·min <sup>-1</sup> ·kg <sup>-1</sup>	1.0±0.1	1.2±0.2	NS
Lactate, mmol/l	1.8±0.3	1.6±0.9	NS
RER	0.93±0.01	0.94±0.01	NS
At 21 km/h			
$\dot{V}CO_2$ , l/min	4.9±0.4	3.9±0.2	<0.0001
$\dot{V}O_2$ , l/min	4.7±0.1	3.8±0.1	<0.005
$\dot{V}O_2$ , ml·min <sup>-1</sup> ·kg <sup>-1</sup>	67.6±4.6	67.8±4.0	NS
$\dot{V}E$ , l/min	120.2±18.6	103.4±13.6	<0.05
$\dot{V}E$ , l·min <sup>-1</sup> ·kg <sup>-1</sup>	1.7±0.3	1.9±0.3	NS
Lactate, mmol/l	9.5±1.3	7.2±1.7	<0.005
RER	1.03±0.04	1.01±0.03	NS
Maximal exercise			
$\dot{V}CO_{2\max}$ , l/min	5.5±0.3	4.0±0.4	<0.0001
$\dot{V}O_{2\max}$ , l/min	5.0±0.4	3.9±0.4	<0.0001
$\dot{V}O_{2\max}$ , ml·min <sup>-1</sup> ·kg <sup>-1</sup>	71.0±5.3	71.5±4.6	NS
$\dot{V}E_{\max}$ , l/min	128.8±16.9	109.9±15.3	<0.05
$\dot{V}E_{\max}$ , l·min <sup>-1</sup> ·kg <sup>-1</sup>	1.9±0.3	2.0±0.3	NS
Lactate, mmol/l	12.8±2.2	8.7±1.7	<0.001
RER	1.16±0.04	1.09±0.03	<0.001
Peak treadmill velocity, km/h	24.2±1.0	23.7±1.3	NS

Values are means ± SD for 9 white and 11 black athletes.  $\dot{V}CO_2$ ,  $CO_2$  production;  $\dot{V}O_2$ ,  $O_2$  consumption;  $\dot{V}E$ , minute ventilation volume; RER, respiratory exchange ratio;  $\dot{V}CO_{2\max}$ ,  $\dot{V}O_{2\max}$ , and  $\dot{V}E_{\max}$ , maximal  $\dot{V}CO_2$ ,  $\dot{V}O_2$ , and  $\dot{V}E$ , respectively.

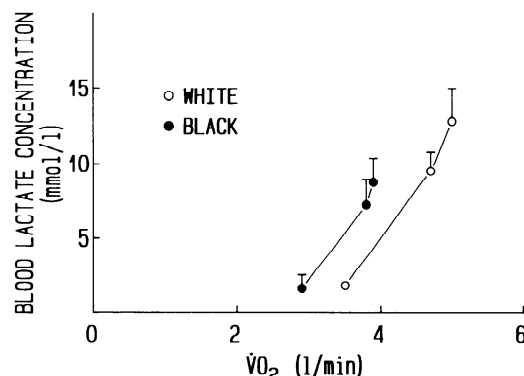


FIG. 3. Rises in blood lactate concentration with increasing  $\dot{V}O_2$  in elite black and white runners. Means ± SD of blood lactate concentrations at different mean  $\dot{V}O_2$  values in 9 white and 11 black athletes were obtained from data presented in Table 4.

was a reasonable correlation between initial peak torque and time to fatigue ( $r = -0.67$ ,  $P < 0.001$ ; Fig. 5).

## DISCUSSION

To our knowledge, this is the first study of elite black and white African runners whose ability over the middle distances (1.65–5 km) were comparable (Table 1). Analysis of the best performances of these athletes showed that whereas the white runners matched the black runners at distances up to 5 km, the black runners were clearly superior at distances >5 km (Table 1, Fig. 1).

Perhaps the outstanding finding of the study was that the superior athletic performance of the black runners

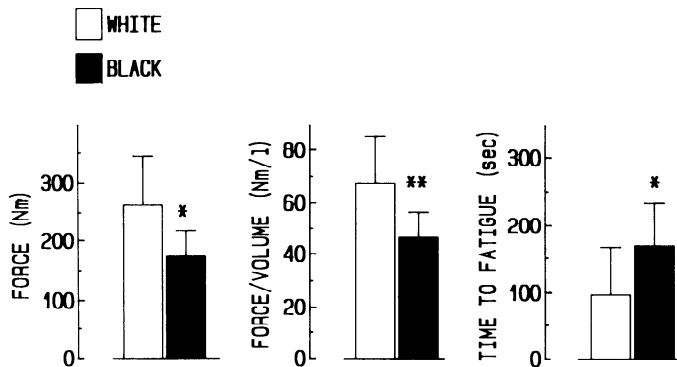


FIG. 4. Right quadriceps isometric contraction peak torque and time to fatigue in elite black and white runners. Means  $\pm$  SD of peak torques developed by 9 white and 11 black athletes are expressed in both absolute terms and relative to differences in their estimated lean thigh volumes (Table 2). Details of measurements of time to fatigue are given in MATERIALS AND METHODS. Significantly different between black and white runners: \* $P < 0.05$ ; \*\* $P < 0.01$ .

was due to their ability to sustain a higher  $\dot{V}O_{2\max}$  with increasing running distance (Fig. 1) and not to differences in  $\dot{V}O_{2\max}$  or running economy (Table 4). These observations support those of Bosch et al. (4). Bosch et al. showed that subelite black runners matched with white runners for best 42-km marathon time had slightly lower  $\dot{V}O_{2\max}$  values than white runners but compensated for this by sustaining a significantly higher  $\% \dot{V}O_{2\max}$  during marathon races.

Interestingly, the black runners in this study also reported that they trained at a higher average exercise intensity than the white runners (Fig. 2). Despite their specialization over shorter distances (Table 1), the white runners spent as little of their total training volume performing high-intensity ( $>80\% \dot{V}O_{2\max}$ ) exercise as other white endurance athletes (12, 23). These data were gathered from personal reports and are therefore potentially less reliable than laboratory-measured data. However, there was no reason to doubt the validity of the training data reported by either group of athletes.

Despite the superior fatigue resistance of the black distance athletes, however, their skeletal muscle fiber composition (Table 2) did not show a preponderance of type I fibers, as might have been expected (13). In both the black and white athletes, there was a high proportion ( $\pm 50\%$ ) of type II fibers, similar to that described for middle-distance runners (13).

Instead, the main anthropometric differences between these runners were that the black distance runners were significantly shorter and lighter than the white middle-distance track athletes and had a considerably smaller muscle mass and lean thigh volume (Table 2). One possible explanation for the superior distance running ability of black runners may therefore be their smaller size. It is a common observation that distance runners are smaller than middle-distance runners (7), but, to our knowledge, why smallness is an asset in distance running has yet to be established conclusively.

The lower absolute  $\dot{V}O_2$  and  $\dot{V}E$  values in the lighter black runners when expressed relative to body weight were not different from those in the white runners (Table 4). Thus, as has been argued elsewhere (20),  $\dot{V}O_{2\max}$  mea-

surements (in  $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ) did not predict the superior running ability of the black runners over the longer distances.

Superior running performances of the black runners at the longer distances were also not explained by an increased running economy. The running economies of the black and white athletes at 17 and 21 km/h were the same when corrected for weight (Table 4).

The only differences in the black runners were their lower blood lactate concentrations after submaximal (21-km/h) and maximal exercise and their lower peak RER (Table 4). Elite Kenyan distance runners have also been found to have lower blood lactate concentrations than Scandinavian distance runners during exercise (1, 6; unpublished observations).

These data suggest that there may have been differences in the rate of blood lactate accumulation in the black and white athletes in this study and that lower blood lactate concentrations at any running speed might have contributed to the superior fatigue resistance of the black athletes.

Although the black and white runners worked at the same relative intensity at each treadmill velocity, the absolute work rates of the black runners were less than those of the white runners. Thus, when plotted against  $\dot{V}O_2$  (l/min), blood lactate accumulation was actually greater in the black athletes than in the white athletes (Fig. 3). Part of the more rapid rise in blood lactate concentration with increasing  $\dot{V}O_2$  in the black athletes may have also resulted from their smaller muscle mass and body size (Table 2). Rises in blood lactate concentration during exercise are not just a function of the differences between rates of lactate production and removal (5, 25, 26): they also depend on the non-steady-state lactate distribution volume, which is smaller in lighter athletes (8, 16, 25, 26).

Traditionally, the lower peak RER in the black runners might be considered to suggest that black runners were not as motivated as white runners to work at maximal intensity (Table 4), but we think this explanation is unlikely. With all the athletes watching each other being tested, there was competition for the best performance. Because short-duration high-speed treadmill runs to ex-

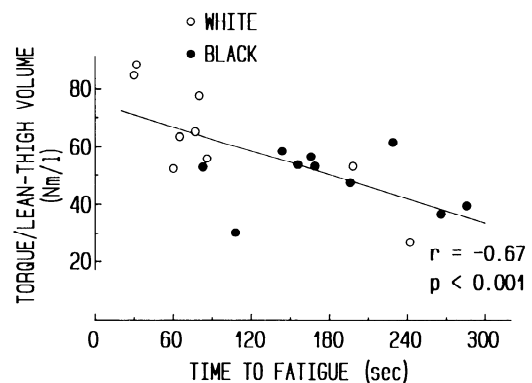


FIG. 5. Relationship between peak right quadriceps isometric contraction torque and time to fatigue in elite black and white runners. Values are individual peak torques developed by 9 white and 11 black athletes expressed relative to lean thigh volume plotted against their times to fatigue, which was measured as described in MATERIALS AND METHODS.

haustion favor middle-distance runners, it is perhaps more surprising that black distance runners were able to equal the performances of the white middle-distance runners. Technical difficulties prevented the measurement of maximal heart rates, which might have provided additional evidence for this interpretation; limitations to the use of the "plateau" phenomenon in determining maximal effort have been described elsewhere (19, 20). Perhaps the lower peak RER values in black athletes were due to a lesser hyperventilatory response to maximal exercise, which in turn was possibly related to their lower blood lactate concentrations.

Interestingly, there were large differences in muscle strength in the black and white athletes (Fig. 4). Even with corrections for estimated lean thigh volume, the peak right quadriceps isometric contraction torques of the black runners were considerably lower than those of the white runners.

In contrast, the times to fatigue were greater in the black athletes than in the white athletes, which resulted in the areas under the fatigue curves of the black and white athletes being similar (Fig. 4). In both groups, there was a significant correlation between initial peak torque and time to fatigue (Fig. 5).

Unfortunately, because there are no elite white distance runners in South Africa to act as controls for the elite black distance runners, the physiological significance of the lower peak torque and increased time to fatigue in the black athletes is difficult to assess. Such differences may or may not explain the superior distance running ability of the black runners.

All we can conclude is that the ability of the elite black runners in this study to both train more intensively and sustain a higher  $\dot{V}O_{2\max}$  during competition was not due to any measurable differences in muscle fiber type composition,  $\dot{V}O_{2\max}$ , or running economy but may have been related to lower blood lactate concentrations at any running speed.

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