Running Science

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Prologue

The Quest for Knowledge in Running

The science of running is undergoing a revolution that has now entered its fifth decade. In the 1970s, exercise physiologists were sure that endurance running was an oxygen game, with oxygen limitation the key cause of fatigue during exercise and $\dot{V}O_2max$ the main physiological variable to be examined.

From a scientific perspective, endurance runners were little more than hearts and leg muscles. The heart was the pump that sent oxygen to the waiting sinews in the lower appendages, and specialized structures in those muscle fibers called mitochondria permitted the muscles to use oxygen to provide the energy necessary for running. Once the limit in that system was reached, anaerobic energy took over, lactic acid built up in the muscles, and the hapless runner was done for the day. A competitor with a better oxygen-delivery and supply system won the race.

In that model, which had its origins in the 1920s at the Harvard Fatigue Laboratory in Cambridge, Massachusetts, where the work of Nobel Prize–winning physiologist A.V. Hill seemed to show that lactic acid could decrease muscular force production, the brain and spinal cord were viewed as just along for the ride, responding meekly to the requests placed by the heart and leg muscles during exercise. If the leg muscles were rollicking along in a steady bath of oxygen, the nervous system sent enough impulses to keep them moving at the requisite rate.

All of this seemed fine until some probing running researchers began to reveal in the 1970s and 1980s that there were other physiological variables that predicted running success. Notably, running economy (i.e., a measure of how stingy runners were with their oxygen) and lactate-threshold velocity (i.e., the velocity above which lactate began to build up in the blood; originally called anaerobic threshold speed) were shown to be relatively reliable predictors of endurance performance.

Limits of $\dot{V}O_2max$ and the Role of the Nervous System

Making matters much worse for the traditional model, studies began to appear that revealed that $\dot{V}O_2max$ was a decent forecaster of performance if one were comparing elite runners with runners in the middle of the pack—but it was weak at foretelling race times among similarly trained runners (e.g., elites, subelites, medium-level runners, and novices). How could that be? After all, endurance running was and still is a truly aerobic sport, with oxygen usage supplying 99 percent of the energy required to run a 10K and oxygen limitation seemingly crucial in determining what can happen in races. Flying in the face of the conventional model, some studies even had the audacity to determine that 300-meter (.19 mi) sprint time—a primarily anaerobic activity—could predict endurance performance far more effectively than maximal aerobic capacity, or $\dot{V}O_2max$.

Thanks to such findings and to brilliant and innovative research, we learned that endurance runners do have nervous systems after all, and that the nervous system plays a profound role in determining the success or failure of both training and competition. The nervous system can create fatigue and actually regulate running pace during endurance training and racing via what is now termed the anticipatory regulation of exercise performance through effort perception. This is part of the revolution in which exercise science is currently immersed. The understanding of the nervous system's role has not only shaken up exercise physiology but has also had a dramatic impact on the training of endurance runners, as the reader will come to understand by reading this book.

The other part of the revolution concerns fatigue itself. Originally thought to be a simple phenomenon related to intramuscular lactic acid, fatigue is now linked with nervous system functioning along with a whole complex of physiological factors such as velocity at $\dot{V}O_2max$, running economy, lactate-threshold velocity, resistance to fatigue, maximal running speed, intramuscular pH, and even muscular potassium levels. The search for the origins of fatigue during running is an important one: When fatigue is understood, the optimal mode of training to limit that fatigue and thus to optimize performance can be researched and implemented.

Science Sheds Light on Running

As a scientist, I love the fact that an understanding of running performance is approachable via the scientific method and that running science has provided so many valuable clues about optimal training. No longer are we completely bound by tradition and myth: We can look to great research carried out by running scientists around the globe in order to plan our training and prepare for our most important races.

I believe that running is intrinsically tied to science, more so than many other sports. If we attempt to understand why Derek Jeter piled up more than 3,000 hits and why Marv Throneberry struggled so much to hit curve balls and catch soft tosses from his second baseman, we are stymied nearly immediately by the simple process of identifying the key variables that should be examined. In running, the factors important for success have been identified; we simply need to understand how they work together and how they can be optimized by training.

Running science has had a major practical impact on training for improved performance. Thanks to research, runners and coaches now understand how changes in the volume, intensity, and frequency of training impact the key performance variables, including neural drive, $v\dot{V}O_2max$, running economy, lactate-threshold velocity, resistance to fatigue, and maximal running speed. They know which running speeds are best for various types of training and which forms of strength training have the largest positive effect on performance.

Thanks to the establishment of the anticipatory regulation model of fatigue, they also know what to do when extreme tiredness strikes during races: Turn up neural drive instead of turning down speed in response to a perceived crisis in the muscles. With confidence and understanding, runners and coaches can now—thanks to science—properly answer key questions such as: How fast should my work intervals be run today? How many miles should I cover in my long run? How should I set up my overall training program? Answers to these questions and others will be provided in this book.

A Peek Into the Book

I thank Human Kinetics for the opportunity to create this book; I had been wanting to write it for a very, very long time. I am both a scientist and runner. My running career began at the age of 2 when I evaded my mother in a backyard chase and concluded that running was a very joyful and liberating activity. Six decades of running have only enhanced my love of the sport: I run nearly every morning with my Siberian Husky, who defies all hypotheses about fatigue and toys with me during both sprints and long efforts. I am now happily the race director of the Lansing Marathon, the manager of a successful team of elite Kenyan athletes, and the CEO of the nonprofit organization Lansing Moves the World.

Over the past three years, I ran nearly every day during the predawn hours and worked on the organization and content of this book after my workouts. *Running Science* is organized in a unique way. Beginning with a look at the genetics of running performance and the biomechanics of running in parts I and II, it then proceeds to describe the physiological factors that are important for performance (part III). The next unit (part IV) covers different training methods, and part V outlines key variables, such as volume, frequency, and intensity, and offers an overview of recovery techniques, periodization, and strength training. Part VI explores training for optimizing performance variables, and part VII explains the molecular basis of training. Part VIII discusses how to prepare for popular race distances. The closing sections of the volume address a number of key issues, including the prevention of running injuries and the health benefits of running (part IX); nutritional supplements, proper eating for running, and weight control (part X); and psychological strategies linked with top performance and even the addictive aspects of running (part XI). I sincerely hope you enjoy this book!

PART I

Genetics and Running

CHAPTER 1

Running's Nature-Versus-Nurture Debate

The years 2011 and 2012 were extremely exciting for middle- and long-distance running: In 2011, Geoffrey Mutai surged to victory in the Boston Marathon in 2:03:02, the fastest marathon time ever recorded, and fellow Kenyan Mary Keitany blazed a new world record of 1:05:50 in the half marathon. In 2012, David Rudisha stormed to a new world record of 1:40.91 for 800 meters at the London Olympic Games. Each time a Kenyan athlete performs in an astonishing manner, the debate seems to begin anew: Is nature or nurture more important for running success?

Runners, coaches, and exercise scientists often wonder whether running performances are determined primarily by genetic factors or by the environment. Fans of distance running speculate whether the current Kenyan dominance of endurance competitions is the result of genetic superiority or an active childhood at higher altitudes in western Kenya. Weekend runners trouble themselves over whether they have the innate capacity (genetic constitution) to break 40 minutes in the 10K. And coaches and exercise scientists may dream of testing athletes genetically to determine potential at different running distances.

Such concerns are much more than curiosities. If performances are indeed primarily shaped by genes, coaches and serious runners will begin using cheek swabs to learn what their DNA determines about their running futures, and deceptive practices such as gene doping could play a prominent role in elite competitions. If the environment rules over genetic composition, runners will optimistically juggle their training programs in hopes of finding the schedules that produce the best possible personal performances, and serious scientific research will begin on exactly *how* East Africans are achieving such amazing levels of running fitness.

Genetic factors include the presence or absence of genes that have an impact on physical performance as well as the interactions between such genes. A runner's environment is composed of training, dietary practices, and social and geographical factors. Training is much more than the faithful following of a workout schedule—it is a complex activity including psychological aspects such as willingness to train and social components such as external motivation and the actual opportunity to exercise consistently. Another important environmental factor is whether the knowledge to create a program that can optimize the physiological and psychological variables important for performance exists.

Genes and Running Performance

Environmental factors and the physiological variables associated with performance are so complex that there is a tendency for many to take the simplistic view that genes are dominant in determining running success.[1] A facile view is that genes can act as magic bullets that propel athletes with the right genetic compositions to inevitable success. As an example, *Scientific American* once predicted that performances at the 2012 Olympic Games would depend on the insertion of key genes into the nuclei of athletes' muscle cells.[2] In a similar vein, a professional rugby team from Australia tested its players for variations in 11 exercise-related genes, believing that training programs specifically suited to each player could then be created.[3] Many exercise scientists have come to believe that athletes can be genetically profiled in order to predict their risk of sustaining specific injuries and their suitability for team positions, roles, and subdisciplines in various sporting activities.[3] There is a belief that an examination of a runner's genes can yield important information about whether he or she should become a sprinter, a middle-distance athlete, or a marathoner. There is also a common perception that East African runners (primarily from Kenya and Ethiopia) have a monopoly on the genes that code for endurance performance.[1]

Proponents of a dominant role for genes, or nature, in determining running performances point to the relatively recent discovery of more than 100 genes that have an impact on physical capacity.[4] Such findings reinforce the idea that an individual's potential for running performance could be largely determined at birth. A runner with the right configuration of this multitude of genes, for example, might have an inborn talent for running that would always elevate him or her above other athletes with less optimal genetic makeup.

At first glance, such thinking does not seem entirely unreasonable. Research has revealed that an individual's genetic makeup has a significant effect on physical characteristics, including body size and shape.[5] Although there are many exceptions to the rule, the best distance runners tend to be relatively short in stature and light in weight with slim calves, factors that probably have some genetic component. Greater height tends to dampen distance-running performance because of added mass: Bone mass increases exponentially as a function of height, instead of linearly, giving the taller runner relatively more dead weight to move around a 10K or marathon course. In general, enhanced body mass, either in the form of fat or non-propulsive muscle mass in the upper body, makes endurance runners less economical and less able to sustain high speeds for continuous periods. Scientific studies also have identified many genes that are linked with greater endurance performance.[6]

Somewhat oddly, the East African dominance of distance running is often cited as further evidence that genes are the strongest determinants of endurance performance.[7] An inescapable fact is that the best middle- and long-distance runners in the world are Africans. Over the last five Olympic Games, from 1996 to 2012, male runners of African origin have captured 11 of the 15 possible gold medals in the 1,500 meters, 5K, and marathon competitions, as well as all 10 gold medals awarded in the 10K and 3K steeplechase events. Males of African origin currently hold 11 of the 12 world records recognized by the International Association of Athletics Federation in events ranging from 800 meters to the marathon, including the 1K, 1.5K, the mile, 2K, 3K, 5K, 10K, 20K, 25K, and the 3K steeplechase.

Such African dominance was not present as recently as 20 years ago when European runners ruled supreme at all competitive distances from 800 meters to the marathon.[8] In 1987, 58 of the 120 runners on the all-time

Stephane Kempinaire/DPPI/Icon SMI

▶ Elite distance running is dominated by runners from East Africa.

top 20 lists of performances in races of 800 meters, 1,500 meters, 5K, 10K, marathon, and steeplechase were European. Just 32 of the 120 best runners of all time were African, and 16 of those 32 were Kenyans. The majority of world-record holders were European.

By 2003 the composition of the lists had changed drastically. There were 67 Kenyans in the top 120 and 102 Africans in all, leaving the entire rest of the world with just 18 slots. The European contribution to the world's-best lists had slipped from 58 runners to only 14.[9] Table 1.1 shows the top 10 male runners for various distances.

Table 1.1 All-Time Top 10 Male Athletes in Various Races

Race distance	Athlete	Time	Country
800 meters	1. David Lekuta Rudisha	1:40.91	Kenya
	2. Wilson Kipketer	1:41.11	Denmark (originally from Kenya)
	3. Sebastian Coe	1:41.73	Great Britain
	3. Nijel Amos	1:41.73	Botswana
	5. Joaquim Cruz	1:41.77	Brazil
	6. Abubaker Kaki	1:42.23	Sudan
	7. Sammy Koskei	1:42.28	Kenya
	8. Wilfred Bungei	1:42.34	Kenya
	9. Yuriy Borzakovskiy	1:42.47	Russia
	10. Timothy Kitum	1:42.53	Kenya
1500 meters	1. Hicham El Guerrouj	3:26.00	Morocco
	2. Bernard Lagat	3:26.34	United States of America (originally from Kenya)
	3. Noureddine Morceli	3:27.37	Algeria
	4. Noah Ngeny	3:28.12	Kenya
	5. Asbel Kiprop	3:28.88	Kenya
	6. Fermin Cacho	3:28.95	Spain
	7. Mehdi Baala	3:28.98	France
	8. Daniel Kipchirchir Komen	3:29.02	Kenya
	9. Rashid Ramzi	3:29.14	Bahrain
	10. Venuste Niyongabo	3:29.18	Burundi
5 kilometers	1. Kenenisa Bekele	12:37.35	Ethiopia
	2. Haile Gebrselassie	12:39.36	Ethiopia
	3. Daniel Komen	12:39.74	Kenya
	4. Eluid Kipchoge	12:46.53	Kenya
	5. Dejen Gebremeskel	12:46.81	Ethiopia
	6. Sileshi Sihine	12:47.04	Ethiopia
	7. Hagos Gebrhiwet	12:47.53	Ethiopia
	8. Isiah Kiplangat Koech	12:48.64	Kenya
	9. Isaac Kiprono Songok	12:48.66	Kenya
	10. Yenew Alamirew	12:48.77	Ethiopia

(continued)

Table 1.1 *(continued)*

Race distance	Athlete	Time	Country
10 kilometers	1. Kenenisa Bekele	26:17.53	Ethiopia
	2. Haile Gebrselassie	26:22.75	Ethiopia
	3. Paul Tergat	26:27.85	Kenya
	4. Nicholas Kemboi	26:30.03	Qatar
	5. Abebe Dinkesa	26:30.74	Ethiopia
	6. Micah Kipkemboi Kogo	26:35.63	Kenya
	7. Paul Koech	26:36.26	Kenya
	8. Zersenay Tadese	26:37.25	Eritrea
	9. Salah Hissou	26:38.08	Morocco
	10. Ahmad Hassan Abdullah	26:38.76	Qatar
Marathon	1. Patrick Makau Musyoki	2:03:38	Kenya
	2. Wilson Kipsang Kiprotich	2:03:42	Kenya
	3. Haile Gebrselassie	2:03:59	Ethiopia
	4. Geoffrey Kiprono Mutai	2:04:51	Kenya
	5. Dennis Kipruto Kimetto	2:04:16	Kenya
	6. Ayele Abshero	2:04:23	Ethiopia
	7. Dunkin Kibet Kirong	2:04:27	Kenya
	7. James Kipsang Kwambai	2:04:27	Kenya
	9. Tsegay Kebede	2:04:38	Ethiopia
	10. Emmanuel Kipchirchir Mutai	2:04:40	Kenya
3000 meter steeplechase	1. Saif Saaeed Shaheen	7:53.63	Qatar
	2. Brimin Kiprop Kipruto	7:53.64	Kenya
	3. Paul Kipsiele Koech	7:54.31	Kenya
	4. Brahim Boulami	7:55.28	Morocco
	5. Bernard Barmasai	7:55.72	Kenya
	6. Ezekiel Kemboi	7:55.76	Kenya
	7. Moses Kiptanui	7:56.16	Kenya
	8. Richard Kipkemboi Mateelong	7:56.81	Kenya
	9. Reuben Kosgei	7:57.29	Kenya
	10. Wilson Boit Kipketer	7:59.08	Kenya

Current as of January 2013.

Source: International Association of Athletics Federations (www.iaaf.org).

The Kenyans and other East Africans were sending shock waves through the endurance-running community with their sizzling performances. The issue was not that the European runners had suddenly begun to run slowly; they were running as fast as they always had. The change occurred because the African runners, particularly the Kenyans, were running extraordinarily fast times.[10] An additional startling fact was that the majority of the Kenyans competing on the world stage were Kalenjins, a rather small tribe of about 3 million people.

Observers of this transformation of the running world have been tempted to conclude that Kenyan runners, and especially Kalenjins, have some inborn capacity for long-distance running. In competitive running, nature seems to be winning out over nurture. Kenyans and other East African runners appear to have the right genes for elite performance. There is indirect evidence this might be true.

The top distance runners emerging from Kenya and Ethiopia, for example, tend to come from distinct regions of those countries (specifically, in Kenya's case, from the areas surrounding Eldoret, Iten, Kapenguria, Kaptagat, and Eldama Ravine in western Kenya), rather than being evenly distributed throughout the countries.[11, 12] In relatively isolated populations, such as in the pockets of endurance-running supremacy in Kenya and Ethiopia, a phenomenon called genetic drift can cause specific genes—including those coding for performance—to increase or decrease in frequency rather dramatically compared with neighboring, less-isolated populations. In areas of Kenya such as Kapenguria, in which a pastoral lifestyle is widely practiced, there might also be a natural selection for genotypes that code for enhanced endurance performance. Such selection would not be likely to occur in Nairobi or Mombasa, parts of Kenya that have produced few international runners, nor would it take place in most urban areas around the world where physical endurance would be a weak predictor of reproductive success.

Analysis of the actions and effects of specific genes has also sometimes suggested that genetic makeup can determine running success. For example, the role played by the angiotensin-converting enzyme (ACE) gene and its variants in determining running performance has received considerable attention in recent years among exercise physiologists, molecular biologists, and sports medicine physicians and researchers.[6] ACE can degrade chemicals that dilate blood vessels and stimulate the production of a vasoconstrictor (a compound that narrows the diameter of blood vessels) called angiotensin II during physical activity.[13] With its strong role in determining blood flow to muscles, ACE might be expected to have an impact on endurance performance, and three studies published in 2005 alone linked certain forms of ACE with greater endurance.[13]

Similarly, research reveals that deactivation of a gene that produces myostatin, a chemical that thwarts muscle growth, results in the appearance of so-called super mice with about twice the normal amount of muscle mass. Another strip of DNA, the PPAR-delta gene, has a profound impact on mitochondrial production inside muscle cells (mitochondria are intracellular sites of energy creation, and research has linked heightened mitochondrial density with increased resistance to fatigue). Manipulation of the PPAR-delta gene in scientific inquiries has resulted in the creation of what are called marathon mice that can run about 70 percent longer and 90 percent farther than unaltered mice. Though the same results may or may not occur in humans, the theory of a gene as a magic bullet is advanced by such investigations.

Testing the Nature-Versus-Nurture Hypotheses

Concluding that genetic differences are the paramount factor underlying endurance-performance success is premature, however. In many cases, further analysis of the actions of specific genes reveals that the effects are not always consistent or that the genes that seem to have the biggest impact on performance are not necessarily monopolized by—or even present in—groups of high-performing endurance runners. Many other possibilities for the determination of performance are apparent. Training, or nurture, is certainly one of those elements; even the biggest advocate of nature over nurture must admit that training plays a large role in determining what the race clock reveals when a runner crosses the finish line. In the East African case, there is considerable evidence that Kenyan training differs dramatically from the training carried out by endurance runners in other parts of the world.[14]

In fact, training is commonly considered to be the most important extrinsic, or environmental, factor affecting performance. Scientists use two techniques in their attempts to disentangle environmental and genetic effects and thus provide answers to the debate over nature versus nurture. One method is to look for evidence of patterns of variation in performance variables (for example, $\dot{V}O_2$max or responsiveness to training) in a population. As long as there is variation for a given performance-related trait, estimating the relative contributions of environmental and heritable (genetic) factors to this variation is possible.

This kind of work can be carried out with families. For example, maximal aerobic capacity ($\dot{V}O_2$max), a physiological variable linked with exercise capacity, can be studied in large populations containing family groups. If $\dot{V}O_2$max varies considerably between families but very little among family members, there is evidence that $\dot{V}O_2$max is strongly determined by genetic factors because individuals in the same family tend to have nearly identical $\dot{V}O_2$max values and are very similar genetically. If $\dot{V}O_2$max varies just as much within families as it does between families, then genetic factors would appear to play a small role in determining $\dot{V}O_2$max. The $\dot{V}O_2$max of one's father, mother, or sibling is not necessarily closer to one's own maximal aerobic capacity than the $\dot{V}O_2$max of the unrelated stranger living across town.

How to Determine $\dot{V}O_2$max

$\dot{V}O_2$max, or maximal aerobic capacity, is a traditional measure of endurance fitness. Usually expressed in milliliters of oxygen per kilogram of body weight per minute ($ml \cdot kg^{-1} \cdot min^{-1}$ as expressed in scientific terms), $\dot{V}O_2$max reflects the heart's ability to pump oxygen to the muscles and the muscles' capacities to use oxygen to provide the energy required for running. $\dot{V}O_2$max is usually measured on a treadmill in an exercise laboratory, with a subject warming up and then progressing to increasingly quicker treadmill speeds or higher treadmill inclinations until a plateau or near plateau in oxygen consumption rate is reached, reflecting underlying heart, muscle, or neuromuscular limitations. This plateau is then termed $\dot{V}O_2$max. Table 1.2 provides varying fitness levels for aerobic capacity in females and males.

Table 1.2 Fitness Levels for Aerobic Capacity* in Females and Males

Females	**AGE**					
	20-29	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**
Superior	49.6 or higher	47.4 or higher	45.3 or higher	41.0 or higher	37.8 or higher	37.2 or higher
Excellent	43.9-49.5	42.4-47.3	39.6-45.2	36.7-40.9	32.7-37.7	30.6-37.1
Good	39.5-43.8	37.7-42.3	35.9-39.5	32.6-36.6	29.7-32.6	28.1-30.5
Fair	36.1-39.4	34.2-37.6	32.8-35.8	29.9-32.5	27.3-29.6	25.9-28.0
Poor	32.3-36.0	30.9-34.1	29.4-32.7	26.8-29.8	24.6-27.2	23.5-25.8
Very poor	32.2-lower	30.8-lower	29.3-lower	26.7-lower	24.5-lower	23.4-lower
Males	**AGE**					
	20-29	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**
Superior	55.5-higher	54.1 or higher	52.5 or higher	49.0 or higher	45.7 or higher	43.9 or higher
Excellent	51.1-55.4	48.3-54.0	46.4-52.4	43.3-48.9	39.6-45.6	36.7-43.8
Good	45.6-51.0	44.1-48.2	42.4-46.3	39.0-43.2	35.6-39.5	32.4-36.6
Fair	41.7-45.5	40.7-44.0	38.4-42.3	35.5-38.9	32.3-35.5	29.4-32.3
Poor	38.0-41.6	36.7-40.6	34.8-38.3	32.0-35.4	28.7-32.2	25.7-29.3
Very poor	37.9 or lower	36.6 or lower	34.7 or lower	31.9 or lower	28.6 or lower	25.6 or lower

*Aerobic capacity is $\dot{V}O_2$max expressed as milliliters of oxygen per kilogram of body weight per minute ($ml \cdot kg^{-1} \cdot min^{-1}$).

Data reprinted with permission from The Cooper Institute, Dallas, Texas, from *Physical Fitness Assessments and Norms for Adults and Law Enforcement*. Available online at www.cooperinstitute.org.

Geneticists interested in performance try to establish in their studies what is called heritability of a trait, or H^2. Without delving deeply into the math, it is possible to say that H^2 is nothing more than the ratio of genetic variance to total phenotypic variance for a specific performance variable. Genetic variance refers to the diversity in a variable, such as $\dot{V}O_2max$, that is produced by actual genetic differences, while phenotypic variance is the total measured heterogeneity (maximal amount of the variable possible) in a variable. For math buffs, the equation for heritability follows:

$$H^2 = V_g/V_p$$

with V_g being the variance due to genetic factors and V_p the total phenotypic variance.

If research reveals that H^2 is something small, for example .1, then one can conclude that genes are playing a small role in setting up the variance—the array of characteristics such as aerobic capacity—that one observes in a population. On the other hand, if H^2 is close to 1.0, then genes are playing a huge role.

The rest of the variation above and beyond H^2 (what geneticists call V_e/V_p, which is environmental variance divided by phenotypic variance) can be attributed to environmental factors, including training. Training can be subdivided into willingness to train, ability to train, opportunity to train, and quality of the overall training program. Additional environmental factors can be cultural in nature (e.g., diet, attitude toward running) or geographic (e.g., altitude, temperature, humidity, wind, running surface).

Research using the heritability model has revealed that heritable, or genetic, factors are important but not exclusive determinants of several physiological variables that contribute to success in endurance running. One investigation found that 48 to 74 percent of baseline submaximal aerobic performance—the ability to sustain continuous exercise without previous training—could be attributed to genetic factors. The same inquiry discovered that responsiveness to training—the degree to which aerobic capacity improved as a result of a specific training stimulus—had an H^2 of 23 to 57 percent.[15]

An additional scientific study detected an H^2 of 38 to 87 percent for maximal aerobic capacity, $\dot{V}O_2max$, a traditional measure of running fitness.[16] Another inquiry estimated that the degree to which $\dot{V}O_2max$ increases in response to exercise has a heritability of about 47 percent, and that anaerobic, or lactate, threshold has a heritability of 55 to 80 percent.[17]

In an important investigation, the performance of mothers, fathers, daughters, and sons on exercise bikes was measured in 86 nuclear families. $\dot{V}O_2max$ turned out to have a heritability of about 51 percent in these individuals. The other 49 percent of the variation might be accounted for by diet, attitude toward exercise, daily activity pattern, or other factors.[18]

Taken together, these wide-ranging values for heritability tell runners and their coaches that genetics *do* play a role in performance; after all, heritability does not drop below 23 percent and can be as high as 87 percent. This is hardly a shocking discovery, however, and it contains no practical information for a runner or coach. It is impossible for an individual to tell to what extent his or her performance is based on genes rather than environment, nor would such knowledge have a significant impact on training, which should always be formulated to be the best, most up-to-date, and most scientifically based regardless of underlying genetic constitution.

Note also that heritability studies have trouble truly differentiating between genetic and environmental factors. Family members share not only their genes but also their environments, which undoubtedly include important dietary and psychological factors. Thus, some unknown portion of the genetic variance H^2 is probably environmental in nature.

Conclusion

The heritability studies referred to in this chapter suggest that an individual's capability for distance running is determined by both genetic and environmental factors, and the exact proportion of influence is unknown. This is certainly logical, because it is unlikely that a runner's performance characteristics would be completely unmarked by either genetic or environmental elements. However, the heritability research has not been carried out with elite athletes, and it does not answer the basic question of whether Kenyan and other African runners enjoy a genetic superiority that causes V_g (i.e., the genetic contribution to performance) to be maximized. To explore these ideas further, chapter 2 discusses a second approach to the genetics of running: an analysis linking specific genes with improvements in performance. Chapter 3 then takes a close look at whether a unique genotype is necessary for achieving elite status as a runner.

CHAPTER 2

Genes That Influence Performance

Most runners and coaches realize that genetic factors affect performance. What is less commonly realized is that heredity can act in two completely different ways. First, specific genes or gene combinations can make certain individuals inherently more fit than others, even in situations in which no training has been carried out. Two sedentary individuals plucked at random from the street would be unlikely to have the same fitness level: One might have a stronger heart, a higher $\dot{V}O_2max$, or reduced perceptions of fatigue during exercise, and these differences could be related to genetic makeup. If the non-trained duo agreed to engage in a 5K run, actual performance would hinge on the inherent physiological variations.

Second, some genes or combinations of genes control the way in which individuals respond to training.[1] Some novice runners adapt dramatically to their training protocols, improving maximal aerobic capacity ($\dot{V}O_2max$) by as much as 80 percent over an 8-week period of serious training. Other, less-fortunate individuals might inch $\dot{V}O_2max$ up by just 5 to 10 percent as a result of the same strenuous training. Finally, some individuals do not seem to respond to training at all; their physiological variables related to performance remain stagnant, even after weeks of hard work.[2] Thus, in a group of untrained individuals, variable responses to training can create situations where individuals who are inherently less fit than others can move far ahead of those who were originally more fit.

Both gene-related inherent fitness and gene-related responsiveness to training play roles in determining ultimate performance potential. Of course, quality of training is also important, but it is a nongenetic factor—unless a gene exists that codes for the ability to set up smart training!

Gene-Related Responsiveness

Researchers have identified a gene that influences how runners respond to training; it is a particular variant of the human angiotensin-converting enzyme (ACE) gene. Having the I variant, or I allele (an allele is simply one possible form of a gene), of the ACE gene tends to improve an individual's sample content of Running Science

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