Genetic Profiles and Prediction of the Success of Young Athletes’ Transition from Middle- to Long-Distance Runs: An Exploratory Study

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The aim of the study was to assess whether an aerobic-favoring genetic profile can predict the success of a shift from middle- to long-distance running. Thirteen elite middle-distance runners were divided into successful and nonsuccessful groups in their shift toward long-distance runs. All the runners began their training program at the age of 14–15, and after 6–7 years, changed focus and adjusted their training program to fit longer running distances. The participants’ personal records in the longer events were set at the age of 25–27, about 3–5 years after the training readjustment took place. The endurance genetic score based on 9 polymorphisms was computed as the endurance genetic distance score (EGDS9). The power genetic distance score (PGDS5) was computed based on 5 power-related genetic polymorphisms. The mean EGDS9 was significantly higher among the successful group than the nonsuccessful group (37.1 and 23.3, respectively, \( p < .005 \), effect size 0.75), while the mean PGDS5 was not statistically different between the 2 groups (\( p = .13 \)). Our findings suggest the possible use of genetic profiles as an added tool for determining appropriate competitive transition and specialization in young athletes involved in early phases of talent development.

Talent detection and early development in sport have been perceived as valuable phases in any long-term sport program aimed at developing elite athletes, and are also considered as being dynamic and interrelated (for example, see 7). A number of genetic (e.g., the composition of the skeletal muscles) and environmental (e.g., the quality of the training program) factors associated with achieving expertise in sport are involved in early phases of talent detection and development. Each factor, as well as the interaction among these factors, influences the chances of the talented young athlete to reach the summit in a given sport (19).

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To assess the progress or regression of the young athlete in early phases of talent detection and development, both researchers and practitioners use a number of measurements, among them the skill level of the athlete, his or her anthropometrics, and his or her physical and psychological attributes (12). Although these measurements are quite popular in early phases of talent detections and development, their use in terms of prediction of future success of the young athlete is questionable (for example, see 20). A number of methodological concerns, among them the lack of knowledge about the maturation level of the athlete who is performing the test (26), the lack of authentic and real-life settings in the protocol used, and the lack of longitudinal data (19), makes it difficult for researchers/practitioners to rely solely on existing measurements in their attempts to predict future success of the talented athlete. Therefore, there is a need to ascertain additional tools that can help researchers and coaches collect relevant data on the ability of talented athletes, thereby enabling them to make better decisions associated with the developmental stages of their athletes.

Due to the limited effectiveness of such measurements in early phases of talent detection and development in sport, young athletes or adolescents can end up specializing in sports events that do not necessarily match their biological, physiological, psychological, and sociological traits. Under such circumstances, gifted and talented young athletes may experience years of stagnation without progressing in their achievements, which may lead these athletes to drop out of elite sports at a young age without realizing their potential. This can be seen especially in sports like running or swimming, where performance can be quantified using time or distance. Often in these sports young athletes start their career performing shorter distances, and then, if not successful, try to succeed in longer distances. For example, a young track athlete with a clear tendency for endurance performance may compete in 800 or 1,500 m in the first years of his or her career. However, he or she may better fit, and may possibly achieve better results, in longer running distances, such as the 5,000- or 10,000-m run, or even the marathon. It is has been found that (a) at very early phases of talent development (e.g., up to age of 14; 15) athletes should be advised to sample a number of sport activities, not only to strengthen their arsenal of athletic abilities and skills, but also to be able to select the sport activity that best fits their attributes, characteristics, and preferences, and (b) late specialization in sport is associated with injury prevention among adolescent athletes (6). However, it seems that one of the key factors of success in most competitive sports is the identification of the most appropriate event that best matches the athlete’s physiological properties at a young age (i.e., around 14; 39). This is especially important given the relatively short time that athletes can maintain peak performance during their career.

It is well documented that elite endurance performance requires enhanced mitochondrial respiratory chain and oxidative capacity (3, 9,11). In contrast, power events such as short sprints depend on anaerobic pathways and the breakdown of intramuscular stored creatine phosphate and adenosine triphosphate (15,40). While the functional significance of genetic factors in determining high-level endurance and anaerobic performance is unclear, there is increasing evidence to suggest that multiple variations in the genetic make-up may modify gene expression and thus contribute to an individual’s success in endurance and power-type sports (21,17,8,38). However, it is still unknown whether different genetic variations can
also distinguish the level of excellence between specific athletic events (e.g., 1,500-vs. 10,000-m run), even if they belong to a similar energy requirement category such as aerobic or anaerobic.

Identifying relevant genes for human athletic excellence is difficult, in part because each causal gene makes only a small contribution to the overall heritability. Therefore, new approaches should be identified that take into account the complexity of the issue. Using a simple model, Williams and Folland (42) computed a so-called “total genotype score” (TGS; ranging from 0 to 100), which reflects an accumulated combination of 23 polymorphisms that were found as candidates for explaining individual variations in endurance performance. Using a similar model, Ruiz et al. (33) developed a power-oriented polygenic profile.

In the current study we collected data on elite international- and national-level Israeli track and field athletes, who started their athletic career as middle-distance runners (i.e., 1,500 m) at adolescence and became among the top all-time Israeli runners at this distance, but later made a change and attempted to excel in the longer 5,000- and 10,000-m runs. The aim of this study, therefore, was to evaluate whether assessment of aerobic-favoring genetic polymorphisms can predict the success or failure of such a transition. The unique situation described in the current study can be used as a platform for discussion on the idea of using a genetic profile as an additional tool in the decision made by athletes and coaches to determine and/or change an athlete’s focus.

**Material and Methods**

**Study Population and Design**

Thirteen male track runners participated in the study. To be included in the study, the runners had to fulfill two conditions: Their best 1,500-m run result was rated among the top 20 all-time Israeli results, and at some point in their athletic career, they made a change and shifted their athletic focus to the longer 5,000-m and 10,000-m runs. The athletes were divided into two groups according to their individual best performance in the 10,000-m run. Group 1, the successful group, which included six athletes with 10,000-m run times rated among the top 20 all-time Israeli results, and Group 2, the nonsuccessful group, which included seven athletes with 10,000-m times that were not rated among the top 20 Israeli all-time results.

All the athletes began their training program at the age of 14–15. The age of 14 is considered to be the transition age from the phase of early involvement in sport (i.e., playing different sports) to the phase in which the athlete focuses on one specific sport, or on one or two events within a selected sport (e.g., 800-m and 1,500-m runs in track and field; 10). At this initial stage of their athletic career, these athletes chose middle-distance running (800–1,500 m) as their main event. In the next 6–7 years, they went through a training program that was aimed at helping them achieve the best possible results in these events. After 6–7 years, while seeking better results, they gradually changed focus and adjusted their training program to fit the longer running distances of 5,000 m and 10,000 m. During the years from the age of 14–15 and throughout their entire career, before and after the transition, they practiced in a carefully planned training program. Although the athletes had worked under different coaches, they all used similar training principles that have
been well established as the appropriate training methods for long-distance runners (i.e., long-distance running, interval running, and high-tempo running). An overall distance of 100–150 km per week was covered by each of the participants. In addition, some light strength training and basic running-coordination drills were performed by each participant about twice a week. The athletes were also subjected to a supervised nutritional program emphasizing carbohydrate consumption. None of the participants suffered from extreme occurrences—such as severe injuries, prolonged illness that deprived him from training, personal crisis, or psychological stress.

All the participants routinely competed in comparable national and international level meets, gaining 10–12 years of experience as competitive track and field athletes. The participants’ personal records in the longer events (see Table 1) were set at the ages of 25–27, about 3–5 years after the training adjustment point.

The study was approved by the Institutional Review Board of the Hillel Yaffe Medical Center, Hadera, Israel, according to the Declaration of Helsinki. A written informed consent was obtained from each participant.

Genotyping

Genomic DNA was extracted from peripheral EDTA-treated anticoagulated blood using a standard protocol. Genotype analyses were performed, as explained below, in the Genetics and Molecular Biology Laboratory of the Zinman College of Physical Education and Sport Sciences at the Wingate Institute. To ensure proper internal control, for each genotype analysis, we used positive and negative controls from different DNA aliquots which were previously genotyped by the same method, according to recommendations for replicating genotype–phenotype association studies (7). For all polymorphisms we used the polymerase chain reaction (PCR), and the resulting restriction fragment length polymorphism (RFLP) analysis was performed by two experienced and independent investigators who were blind to the subject data.

Table 1  Athletes’ Mean Results in 800- to 10,000-m Runs in Min and Sec

<table>
<thead>
<tr>
<th></th>
<th>800 m</th>
<th>1,500 m</th>
<th>3,000 m</th>
<th>5,000 m</th>
<th>10,000 m</th>
</tr>
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<tbody>
<tr>
<td>Successful</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>01:51.49</td>
<td>03:47.22</td>
<td>08:02.44</td>
<td>14:07.72</td>
<td>29:41.53</td>
</tr>
<tr>
<td>SD</td>
<td>00:03.68</td>
<td>00:07.17</td>
<td>00:13.08</td>
<td>00:32.94</td>
<td>00:59.75</td>
</tr>
<tr>
<td>Nonsuccessful</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>01:51.19</td>
<td>03:48.68</td>
<td>08:30.77</td>
<td>15:07.00</td>
<td>32:04.78</td>
</tr>
<tr>
<td>SD</td>
<td>00:00.87</td>
<td>00:03.90</td>
<td>00:19.51</td>
<td>00:14.74</td>
<td>00:38.22</td>
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<td>t test</td>
<td>.900</td>
<td>.218</td>
<td>.013</td>
<td>.005</td>
<td>.001</td>
</tr>
</tbody>
</table>
Genetic Profiles and Athletic Performance

Genotype Scores

We computed the combined influence of nine endurance polymorphisms (detailed in Table 2) based on a previously used model (33,35,42). First, we scored each genotype within each polymorphism. We assumed an additive model (equaling 0, 1, or 2), based on the number of alleles associated with a higher potential for endurance performance that was carried by each subject for each polymorphism. Thus, we assigned a genotype score (GS) of 2, 1, or 0 to each individual genotype, theoretically associated to the highest, medium, or lowest potential for endurance performance, respectively. Second, we computed the endurance genetic distance score for nine genetic polymorphisms (EGDS9), which is the Euclidean distance from the perfect genetic score for these polymorphisms. EGDS9 = \(\sqrt{(2–GS_{PPARGC1A})^2 + (2–GS_{PPARA intron 7 G/C})^2 + (2–GS_{NRF2 A/G})^2 + (2–GS_{NRF2 A/C})^2 + (2–GS_{SHIF C/T})^2 + (2–GS_{NRF2 I/D})^2 + (2–GS_{ACTN3 C/T})^2 + (2–GS_{ACE I/D})^2}\). Third, the EGDS was transformed to a 0–100 scale for easier interpretation, as follows: EGDS9 = 100–(100/9) × (\(\sqrt{(2–GS_{PPARGC1A})^2 + (2–GS_{PPARA intron 7 G/C})^2 + (2–GS_{NRF2 A/G})^2 + (2–GS_{NRF2 A/C})^2 + (2–GS_{SHIF C/T})^2 + (2–GS_{NRF2 I/D})^2 + (2–GS_{ACTN3 C/T})^2 + (2–GS_{ACE I/D})^2}\)), where 36 is the result of multiplying 9 (the number of studied polymorphisms) by 4, which is the score given to the “worst” genotype. An EGDS9 of 100 represents an “optimal” endurance genetic profile, that is, all GS’s are 2. In contrast, an EGDS9 of 0 represents the “worst” possible profile for endurance genetic profile, that is, all GS’s are 0. In the same way, we computed the Power Genetic Distance Score for 5 genetic polymorphisms (PGDS5) based on five power-related genetic polymorphisms (33; described in Table 2). Finally, we computed the EGDS9/PGDS5 ratio for each group.

Statistical Analysis

We used an unpaired student’s t test to compare running time EGDS9 and PGDS5 scores between successful and nonsuccessful athletes. Data are shown as mean ± SD. Statistical significance was set at \(p\) value < 0.05.

Results

The runners’ personal-best results in the distances from 800 m to 10,000 m are presented in Table 1. There was no statistically significant difference in the mean 800-m and 1,500-m run results between the successful and nonsuccessful groups (\(p = .90\) and \(p = .22\) in the 800-m and 1,500-m run, respectively). The mean results in the 3,000-, 5,000-, and 10,000-m running results were significantly faster among the successful group than among the nonsuccessful group (\(p < .05\), \(p < .01\), \(p < .001\) in 3,000 m, 5,000 m, and 10,000 m, respectively).

The athletes’ EGDS9 and PGDS5 are shown in Figure 1. The mean EGDS9 was significantly (\(p < .005\)) higher in the successful group (37.1) than in the nonsuccessful group (23.3), while there was no difference in mean PGDS5 between the groups (\(p = .13\)). Moreover, when the athletes were graded according to their EGDS9, we found that in most cases there was a match between the athlete’s EGDS9 and their categorization as successful or nonsuccessful (Figure 2). Namely, the successful athletes’ EDGS9 ranged between 33.3 and 47.3, while nonsuccessful athletes’ EDGS9 ranged between 15.0 and 35.4.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Gene</th>
<th>Polymorphism</th>
<th>Genotype (2= “optimal” genotype)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRF2</td>
<td>nuclear respiratory factor 2</td>
<td>A/C (rs12594956)</td>
<td>0=CC, 1=AC, 2=AA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A/G (rs7181866)</td>
<td>0=AA, 2=AG and GG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C/T (rs8031031)</td>
<td>0=CC, 2=CT and TT</td>
</tr>
<tr>
<td>PPARA</td>
<td>peroxisome proliferator-activated receptor alpha</td>
<td>Intron 7 G/C (rs4253778)</td>
<td>0=CC, 1=CG, 2=GG</td>
</tr>
<tr>
<td>PPARD</td>
<td>peroxisome proliferator-activated receptor delta</td>
<td>T294C (rs2016520)</td>
<td>0=TT, 1=CT, 2=CC</td>
</tr>
<tr>
<td>PPARGC1A</td>
<td>peroxisome proliferator-activated receptor gamma, coactivator 1, alpha</td>
<td>Gly(G)482Ser(S) (rs8192678)</td>
<td>0=SS, 1=GS, 2=GG</td>
</tr>
<tr>
<td>HIF</td>
<td>hypoxia inducible factor</td>
<td>C/T (rs11549465)</td>
<td>0=CC, 1=CT, 2=TT</td>
</tr>
<tr>
<td>ACE</td>
<td>angiotensin converting enzyme</td>
<td>I/D (rs1799752)</td>
<td>0=DD, 1=ID, 2=II</td>
</tr>
<tr>
<td>ACTN3</td>
<td>alpha-actinin-3</td>
<td>R/X (rs1815739)</td>
<td>0=RR, 1=RX, 2=XX</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACE</td>
<td>angiotensin converting enzyme</td>
<td>I/D (rs1799752)</td>
<td>0=II, 1=ID, 2=DD</td>
</tr>
<tr>
<td>ACTN3</td>
<td>alpha-actinin-3</td>
<td>R/X (rs1815739)</td>
<td>0=XX, 1=RX, 2=RR</td>
</tr>
<tr>
<td>IL6</td>
<td>interleukin-6</td>
<td>-174 G/C (rs1800795)</td>
<td>0=CC, 1=GC, 2=GG</td>
</tr>
<tr>
<td>NOS3</td>
<td>endothelial nitric oxide synthase 3</td>
<td>-786 T&gt;C (rs2070744)</td>
<td>0=CC, 1=TC, 2=TT</td>
</tr>
<tr>
<td>AGT</td>
<td>angiotensinogen</td>
<td>Met235Thr (rs699)</td>
<td>0=TT, 1=TC, 2=CC</td>
</tr>
</tbody>
</table>
Figure 1 — Endurance genetic distance score (EGDS9) and power genetic distance score (PGDS5), successful vs. nonsuccessful. Each column represents the mean ± SD t test; *p < .05 successful athletes’ EGDS9 vs. nonsuccessful athletes’ EGDS9, **p < .05 nonsuccessful athletes’ EGDS9 vs. nonsuccessful athletes’ PGDS5.

Figure 2 — Endurance genetic distance score (EGDS9) of all participants, successful and nonsuccessful.
Since PGDS5 is composed of five polymorphisms, and EGDS9 is composed of nine polymorphisms, a numerical comparison between the two scores in each group cannot be made. However, when we calculated the ratio of EGDS9/PGDS5 of each group, we found that the mean EGDS9/PGDS5 ratio of the successful group (0.86 ± 0.19) was significantly higher compared with the mean EGDS9/PGDS5 ratio of the nonsuccessful group (0.49 ± 0.16; \( p < .005 \)).

**Discussion**

The main finding of this study is that the young-adult middle-distance runners who made a successful shift to long-distance running at some point in their athletic career carry a higher EDGS9 than the middle-distance runners who did not succeed in this shift. In addition, the PDGS5 was not statistically different between the successful and the nonsuccessful group, emphasizing that it is the endurance and not the anaerobic/power polygenic score that may contribute to a successful runner’s decision to make a competitive change from middle- to long-distances running. This notion is emphasized by the finding that the EGDS9/PGDS5 ratio of the nonsuccessful group was significantly lower compared with the successful group’s EGDS9/PGDS5 ratio, suggesting an unfavorable endurance genetic score that may predict their inability to excel in long-distance running events.

The current prevalent view is that although specialized training and other environmental factors—such as training facilities, personal equipment, nutrition, and familial support—are crucial for the development of elite performance, a favorable genetic predisposition is essential for producing a top-level athlete. However, even an individual with the most favorable genetic profile will not develop into a top-level athlete without proper training. Training in itself may be considered as an extreme self-imposed environmental exposure, and the development of a top-level athlete serves as an example of a gene-environment interaction (5).

Predicting success in sport at early phases of talent development is of interest to both researchers and practitioners. However, it is difficult to predict the future success of the young athlete, because there are number of factors involved in the multiyear talent development process, among them biological, physical, physiological, and psychological factors (23). In addition, there are number of key environmental factors associated with talent development in sport, such as the quality of the training program and the facilities available for the young athlete. Attempting to predict athletic success in aerobic-type events is particularly challenging, because the physiologic aerobic trainability of children is much less than that of adults (32,41). Endurance training increases VO\(_{2}\text{max}\) in children but tends to result in an improvement that is only one-third of that seen in adults (28). While some biological traits, such as the mature physical makeup, cannot be predicted at young ages, the genetic background may be illuminated at any age. Peak performance in aerobic-type events such as the 5,000-m and 10,000-m run is usually obtained at the relatively advanced age of 27–30 years (compared with peak performance in middle distance 800 m and 1,500 m runs, obtained at the age of 24; 37), after years of training. In light of this, the use of genetics as a tool to direct young athletes to the sport that best matches their biological traits seems valuable. This unique tool may also assist coaches in building effective training programs for the young developing athletes.
The Human Gene Map for Performance and Health-Related Fitness Phenotypes (2006–2007 update; 4) describes more than 200 genes that may be related to athletic performance. Twenty-three of them were found to be strongly related to endurance performance (17). In our model of favorable endurance genetic profiles, we chose nine polymorphisms, six of them related to mitochondrial biogenesis (13; PPARGC1A Gly482Ser, PPARA intron 7 G/C, PPARD T294C, NRF2 A/G, NRF2 A/C, NRF2 C/T) and one to the hypoxia inducible factor (HIF). The remaining two SNPs are the α-actinin-3 R577x and the ACE I/D, which are important for both endurance and power sports.

Mitochondrial function is associated with aerobic performance. Peroxisome proliferator activated receptor (PPAR)-delta (gene PPARD) and PPAR-gamma coactivator 1 alpha (gene PPARGC1A) are determinants of mitochondrial function. PPAR-delta, in particular, regulates the expression of genes involved in lipid and carbohydrate metabolism and modifies insulin sensitivity-related skeletal muscle glucose uptake. A functional $\rightarrow$294T/C polymorphism in this gene is also associated with endurance performance predisposition (1). The nuclear respiratory factors NRF1 and NRF2 coordinate the expression of nuclear and mitochondrial genes responsible for mitochondrial biogenesis and respiration. Carriers of a polymorphism in the sequence of translation initiator ATG in the NRF2 gene have higher training response and improved running economy than noncarriers, thus potentially explaining some of the interindividual variance in endurance capacity (18). In addition to mitochondrial biogenesis related genes, HIF also contributes to athletic endurance performance. HIF-1 alpha is the primary transcriptional response factor for acclimation to hypoxic stress, by up-regulating glycolysis and angiogenesis response to low levels of tissue oxygenation. Some of the genes that are controlled by HIF's encode proteins that stimulate red cell production (mainly erythropoietin; 27).

The ACTN3 gene plays a role in both power- and endurance-oriented phenotypes. The ACTN3 gene encodes for the synthesis of a-actinin-3 in skeletal-muscle fibers, a sarcomeric protein necessary for producing “explosive” powerful contractions. A premature stop codon polymorphism [Arg(R)577Ter(X), rs1815739] in ACTN3 was first described by North et al. (31). A lack of the a-actinin-3 XX genotype is believed to increase α-actinin level and produce top-level athletic performance in “pure” power sports like sprinting and jumping (46). However, compared with the general population, the X allele tends to be over-represented in elite endurance athletes (22,46). A mechanistic explanation for the latter finding might be found in the α-actinin-3 knockout (KO) mouse. Compared with wild-type mice, the muscles of the KO mouse exhibit 33% higher endurance and a shift toward increased activity of mitochondrial oxidative metabolism (24,25).

The ninth gene in our EGDS9 model is the angiotensin I converting enzyme (ACE), which is also part of PGDS5. The ACE I/D polymorphism (rs1799752) is arguably the most extensively studied genetic variation with regard to exercise-related phenotypes, and is related to cardiovascular and skeletal muscle function. An excess of the I allele has been associated with some aspects of endurance performance (36). Conversely, an excess of the D allele has been reported among elite athletes in more power-oriented events (30). The mechanism underlying the association of the D allele with power-oriented, anaerobic sports is most likely mediated through differences in skeletal muscle strength gain (14). Conversely, the
I allele may influence endurance performance through improvements in substrate delivery (44) and the efficiency of skeletal muscle (43), with subsequent conservation of energy stores (29).

In addition to the ACE and ACTN3 genes, the PGDS5 is also based on IL6 and NOS3. The IL6-174 G/C polymorphism is associated with power sport performance, with the G allele exerting a favorable effect with no effect on endurance performance (34). This could be due to the improved muscle repair response after eccentric damage that is associated with the G allele (45). The NOS3 gene encodes NO synthase. The T786C mutation of the NOS3 polymorphism (rs2070744) is associated with elite power sport performance, where the mutant C allele would exert its favorable effect on power performance through the muscle hypertrophic stimulus brought about by NO-mediated vasodilatation (16).

Our finding that middle-distance runners who made a successful shift to competing in long-distance running carry a higher EDGS9 than middle-distance runners who did not succeed in this shift, suggests the possibility of using a genetic profile as an additional tool that may assist athletes and coaches in determining appropriate competitive transition and athletic specialization.

Recently, Appell Coriolano and Duarte (2) indicated that performance and genetic polymorphism studies often yield conflicting results. They suggested that even if significant associations were found, it does not indicate, for example, that an individual carrying a specific favorable genotype would necessarily develop a great sprinting career. One has to take into account that any phenotype reflects a complex interaction of multiple factors, including genes, environment, and epigenetic factors as well as gene-gene and gene-environmental interactions. We are aware of the very small sample size in our present exploratory/case study. This was due to the uniqueness of the study population—elite middle-distance runners from the age of puberty to early adulthood who later made a competitive transition to long-distance running. However, the study results may be used as an eye opener, suggesting the idea that a polygenetic EDGS profile may provide a partial explanation for the athletes’ ability to excel or fail in a specific aerobic performance. Thus, a genetic polymorphism may help athletes and coaches to complete a missing piece in the puzzle of predicting human competitive performance. This may be used not only for event transitions, but also for appropriate and ethically sound athletic direction from very young ages.

In summary, although it is recognized that a single polymorphism cannot determine an athlete’s ability to succeed or fail in a certain athletic event, our findings suggest that a high EDGS9 may play a role in a successful competitive transition and athletic specialization. Moreover, the lack of a difference in PDGS5 between runners who succeeded in the shift toward long-distance runs and those who did not, suggests that it was their favorable aerobic genetic profile that played a role in their ability to successfully make the transition from middle- to long-distance running.

Larger-scale research, preferably in other ethnic cohorts, is needed to establish a valid genetic score that would help in predicting success in sport. However, the present exploratory study, which described a unique situation, may raise the idea of genetic profiling as an additional tool to assist in predicting the success of a transition from middle- to long-distance running events. Such transition is a career changing decision for athletes, and therefore, additional supporting tools may be of great benefit. Finally, it should be noted that while a favorable genetic predis-
position is important, many other environmental and psychological factors—such as training facilities, personal equipment, nutrition, familial support, and motivation—in addition to socioeconomic factors, are crucial for the development of a top-level athlete. Furthermore, the potential use of genetic predisposition in very young athletes (e.g., at around age of 14, when selection of one sport activity is typically made), may raise a number of ethical issues. For example, how do coaches deal with those young athletes who lack the specific genetic profile but are highly motivated to achieve? Should young athletes be told that they don’t have the good genetic profile required to reach the summit in their sport? If the answer to the second question is positive, how should this information be delivered to the young athlete without hampering his or her motivation to be involved in sport over a long period of time? Policymakers who are involved in youth sports should be aware of these issues, and therefore develop a sport policy that will account for an appropriate use of genetic profiles in early phases of talent development.

**References**


