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Influence of DNA-Based Performance in Sports

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Abstract

Sports performance results from the interplay of a combination of genetic, physiological, psychological, environmental, and socio-cultural factors. More and more, genetics has become a field of study in sports science in recent years, revealing the biological origins of athletic ability (Ahmetov & Fedotovskaya, 2022; Semenova et al., 2023). Performance analysis based on DNA demonstrates the impact of genetic variations on endurance capacity, muscle fiber makeup, recovery capability, psychological strength, and the propensity for injury (Guth & Davies, 2013; Pickering & Stevens, 2017).However, specific genes are heavily related to power and endurance—ACTN3 and ACE**,** or skill acquisition, strong connective tissue, and our bodies' way of handling energy—BDNF**,** COL1A1, and PPARGC1A (Ginevičienė et al., 2016; Naureen et al., 2016). The highlighted aspects make it possible to create an individual training schedule, strengthen the body's weak points, and make menus for athletes based on genetics (Pickering & Stevens, 2017; Semenova et al., 2023). Nevertheless, incorporating genetic information into sports has crucial drawbacks comprising ethical dilemmas, "genes make the final decision," intrusion into privacy, and disparities, both socio-economic and ethical (Naureen et al., 2016; Semenova et al., 2023; Genetic Markers of Sports Performance, 2025).This paper describes the scientific background, real-life perspective, and ethical considerations of DNA-based sports performance. I believe that while genetics can positively influence training and the well-being of an athlete, the results must be seen regarding the two opposing principles—that biological potential must always be balanced with ethical and environmental responsibility.

Key words : Sports genomics, Athletic performance, ACTN3 gene, ACE gene, Genetic variations, muscle type

Introduction

The pursuit of excellence in sports is motivated by the wish to explore to the limit human physical and psychological potential. Conventional performance determinants include training methodologies, environmental conditions, and the psychological preparedness of individuals. With the mapping of the human genome and the rise of molecular biology, genetics has emerged as an important player.

Sports genomics is the scientific study of the impact of genetic variation on physical activity patterns. Predispositions and limitations associated with each athlete's genotype include endurance, power, recovery, and injury risk. While it is appropriate that no gene determines successful performance, people with certain genetic profiles excel in certain sports. It is essential to explore the effect of DNA-based factors on sports performance, outline practical consequences, and explore the difficulties encountered in greater detail.

Genetic Basis of Sports Performance

1. Muscle Function and Performance

- **ACTN3 Gene:** Known as the *"speed gene,"* ACTN3 influences how fast-twitch muscles work. Athletes with the RR genotype demonstrate superior sprinting and explosive power abilities, while those with the XX genotype may show advantages in endurance sports due to a greater reliance on slow-twitch fibers (North et al., 1999; Yang et al., 2003; Ginevičienė et al., 2016).
- **ACE Gene:** The I allele variant promotes enhanced oxygen utilization and cardiovascular efficiency, favoring endurance athletes, while the D allele variant is associated with strength and power, making it prevalent in sprinters and throwers (Montgomery et al., 1998; Woods et al., 2001; Ahmetov & Fedotovskaya, 2022).

2. Energy Metabolism and Endurance

- **PPARGC1A:** Regulates mitochondrial biogenesis and how the body uses oxygen to create energy—key determinants of endurance capacity. Athletes with favorable variants exhibit superior aerobic power and improved oxidative metabolism (Lucia et al., 2005; Eynon et al., 2013; Ginevičienė et al., 2016).
- **Mitochondrial DNA (**mtDNA**):** Since mitochondria are central to energy production using oxygen, variations in mtDNA can affect stamina, recovery, and adaptation to endurance training. Specific haplogroups have been associated with enhanced aerobic performance (Niemi & Majamaa, 2005; Murakami et al., 2002).

3. Connective Tissue Integrity and Injury Risk

- **COL1A1 and COL5A1 Genes:** Influence the structure and strength of tendons and ligaments. Variations in these genes can predispose athletes to injuries such as tendon ruptures or ligament tears. Identifying such risk allows for preventive strategies and targeted conditioning (Posthumus et al., 2009; Collins & Raleigh, 2009; September et al., 2008).

4. Neuropsychological Traits

- **BDNF (Brain-Derived Neurotrophic Factor):** Regulates the brain's ability to adapt (neuroplasticity), motor learning, and stress response. Favorable variants (e.g., Val66Met polymorphism) may enhance focus, resilience, and skill acquisition in athletes (Hopkins et al., 2011; Seifert et al., 2010; Walsh et al., 2017).
- **COMT and DRD4 Genes:** Linked to how dopamine is controlled, they influence motivation, aggression, reward sensitivity, and emotional control during competition. Variations in these genes may explain individual differences in mental toughness and performance consistency under pressure (De Moor et al., 2006; Tartar et al., 2012; Strobel et al., 2011).

Applications of DNA-Based Insights in Sports

1. Talent Identification

By analyzing genetic tendencies, coaches and talent scouts can identify young athletes with potential for endurance, sprinting, or technical sports (Ruiz et al., 2009; Ahmetov & Fedotovskaya, 2022). However, genetics should only complement—not replace—traditional performance assessments based on skill, motivation, and training environment (Pitsiladis et al., 2016).

2. Personalized Training and Recovery

Genetic analysis helps tailor training loads and recovery strategies. For example, athletes with ACTN3 XX gene types may benefit from endurance-oriented training, while those with RR genotypes may respond better to strength and sprint conditioning (Yang et al., 2003; Pickering & Kiely, 2019). Moreover, variants related to inflammation and oxidative stress (e.g., IL6, SOD2) can inform individualized recovery protocols (Eynon et al., 2013).

3. Nutritional Interventions

The study of gene–nutrition interactions (*nutrigenomics*) allows for personalized dietary strategies (Guest et al., 2019). For instance, athletes with specific CYP1A2 gene variants, which influence caffeine metabolism, may benefit from adjusted supplementation strategies (Womack et al., 2012; Guest et al., 2018). Similarly, PPARGC1A and FTO gene variants can affect energy metabolism and fat utilization (Lucia et al., 2005).

4. Injury Prevention and Rehabilitation

Gene testing for collagen-related genes such as COL1A1 and COL5A1 can identify athletes at higher risk of ligament and tendon injuries, guiding preventive strength and flexibility programs (Collins & Raleigh, 2009; Posthumus et al., 2009). Knowledge of genetic susceptibility supports individualized rehabilitation and load management.

5. Psychological Training

Genes influencing stress regulation and mental performance can provide insight into mental preparation strategies. For example, BDNF**,** COMT, and DRD4 gene variants are associated with stress response, motivation, and emotional control (De Moor et al., 2006; Strobel et al., 2011; Walsh et al., 2017). Athletes with a predisposition to higher anxiety levels may benefit from targeted psychological interventions and resilience training (Hopkins et al., 2011).

6. Ethical, Legal, and Social Considerations

While DNA-based performance analysis offers exciting opportunities, several concerns must be addressed:

- **Genetic Privacy:** DNA is highly sensitive personal data, and misuse in athlete contracts or team selection poses ethical risks (Camporesi et al., 2015; McNamee et al., 2009).
- **Genetic Discrimination:** There is a danger that athletes could be unfairly excluded from opportunities due to genetic test results (Hogarth et al., 2015).
- **Equity in Sports:** Access to genetic testing is expensive, potentially widening the gap between wealthy and resource-limited athletes or nations (Pitsiladis et al., 2016).

- **Genes vs. Growth:** Overemphasis on genetics risks undermining the role of training, coaching, environment, and psychological resilience in sports performance (Pickering & Kiely, 2019).

Conclusion

DNA-based performance research has expanded the understanding of human athletic potential by identifying gene indicators that influence strength, endurance, recovery, and psychological resilience. While these insights allow for more precise talent identification, training personalization, and injury prevention, they should not be misinterpreted as predictors of athletic destiny. Success in sports remains the product of both genetics (nature) and training, motivation, and environment (nurture). To responsibly use DNA information in sports, ethical safeguards and education are essential. In the future, genomics, when combined with sports science and psychology, will support holistic athlete development and safer, more efficient training practices.

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