NEW APPROACHES IN SPORTS SCIENCES

THEORY, METHOD, AND PRACTICE

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Assoc. Prof. Dr. Mehmet ALTIN

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Chapter 1

An Overview of the Fundamental Principles of Sports Genetics

Onur ORAL[1*], Iyanuloluwa OJO[2], Naima BADID[3]

1.The Basics of Sports Genetics

The evolution of genetics as a scientific discipline has been instrumental in reshaping our understanding of human physiology and athletic performance. From the inception of Mendelian genetics in the mid-19th century to modern genomic analysis, researchers have consistently sought to unravel the complexities of hereditary and environmental influences on sports performance (Hartl & Jones, 2009). Modern sports genetics is now poised to integrate genetic predispositions with lifestyle and training methodologies, thereby fostering personalized approaches to athlete development and talent identification (Pitsiladis et al., 2016; Williams et al., 2016).

Understanding the underpinnings of genetics has long been central to elucidating how biological information is stored, transmitted, and expressed within organisms. Genes, defined as specific regions within DNA, serve as the primary units of inheritance, encoding the information that drives the synthesis of proteins—molecules critical for virtually every cellular function (Pasternak, 2005). In its double-helical structure, DNA comprises a chain of nucleotides whose precise sequences dictate amino acid arrangements in proteins via the genetic code. This direct relationship, whereby the nucleotide sequence corresponds to protein structure, underlies all biological function and phenotypic expression (Pasternak, 2005; Tar & Gergely, 2021).

At its core, genetic function is anchored in the process of replication, in which one strand of DNA serves as the template for the synthesis of a new complementary strand. This mechanism not only guarantees the faithful

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transmission of genetic information from one generation to the next but also establishes the framework within which mutations may occur, leading to altered protein structure and function (Bouchard et al., 1992). Such mutations can have profound consequences on cellular processes, contributing both to the diversity observed among organisms and to the manifestation of various phenotypes, including those relevant to athletic performance (MacArthur & North, 2004).

While classical genetics provides the foundation for understanding biological inheritance, sports genetics represents a specialized intersection of genetic science and human performance. This branch of study investigates how genetic factors influence an athlete's strength, endurance, muscle characteristics, and overall physical performance. It is well recognized that the interaction between genetic predispositions and environmental factors—such as training intensity, nutrition, and lifestyle—profoundly shapes athletic outcomes (Yang et al., 2024). For instance, although genes play a role in determining an individual's stature or muscle fiber composition, the environmental inputs during developmental years, including childhood nutrition and physical activity, are equally significant (Bouchard et al., 1992).

Studies of sports genetics have employed diverse research methodologies. Twin studies and family investigations have consistently demonstrated that genetic variability is responsible for much of the inter-individual differences in physical performance parameters, including maximal oxygen uptake (VO2 max), a critical determinant of endurance (Bouchard et al., 1992). In such studies, monozygotic (identical) twins often exhibit similar baseline genetic endowments; however, their responses to standardized training loads can differ dramatically—at times, by factors as high as six to nine times—underscoring the complex interplay between genes and environment (Bouchard et al., 1992; McNamee et al., 2009).

Complementary to twin and family studies, genetic mapping has advanced our understanding of the spatial organization of the human genome and helped identify regions linked to performance traits. With approximately 30–40 thousand genes encoded in human DNA, mapping these genetic loci has allowed researchers to correlate specific genomic regions with distinct phenotypic characteristics. For example, gene mapping studies have aimed to pinpoint the location of candidate genes that exhibit strong associations with traits like muscle mass, speed, and endurance (Tar & Gergely, 2021). Such studies typically involve the identification of quantitative trait loci (QTL) that exhibit statistically significant effects on athletic performance.

The field of sports genetics examines the intricate relationships between genes, environmental factors, and athletic achievement. At its core, genetic predisposition serves as a foundation upon which external influences such as nutrition, training intensity, and lifestyle choices build to shape an athlete's performance (Puthucheary et al., 2011; Semenova, Hall & Ahmetov, 2023). Genetic studies, including twin studies and candidate gene research, have provided compelling evidence that heredity contributes significantly to traits like muscle fiber composition, endurance capacity, and even injury susceptibility (Bouchard et al., 1992; Rankinen et al., 2006). However, the exact contribution of genetics versus environmental factors remains a dynamic area of investigation, underlining the multifactorial nature of athletic performance (Ostrander et al., 2009).

One of the most notable examples within sports genetics is the exploration of the angiotensin-converting enzyme (ACE) gene and the alpha-actinin-3 gene (ACTN3) gene. The ACE gene has been linked to cardiovascular efficiency and endurance performance. Studies have indicated that specific variants of the ACE gene enhance oxygen utilization during prolonged exercise, thereby contributing to superior endurance capacity (Hughes et al., 2011; Montgomery et al., 2002; Silva et al., 2024). In contrast, the ACTN3 gene, often termed the "sprinter's gene," is associated with muscle power and speed. This gene encodes an actin-binding protein crucial for fast-twitch muscle fibers, and its functional variant is commonly observed among elite athletes in power and sprint-based sports (Ahmetova et al., 2016; Puthucheary et al., 2011). The dichotomy between these two genes provides a framework for understanding how genetic predispositions can predispose athletes to excel in specific sporting disciplines.

Beyond these individual genes, gene mapping studies have significantly advanced our comprehension of sports genetics. With the human genome consisting of approximately 30,000 to 40,000 genes, identifying the key genetic markers that contribute to athletic performance involves a systematic approach to locate and understand these genes (Guest et al., 2019). These studies commonly utilize high-throughput genetic sequencing and advanced statistical analyses to correlate gene variants with phenotypic traits such as muscle mass, strength, and cardiopulmonary function (MacArthur & Ahmetova et al., 2016; Rankinen et al., 2006). The goal is to decipher the genetic blueprint that contributes to an athlete's physiology, thereby enabling the development of personalized training regimens that account for individual variability (Pitsiladis et al., 2016).

A critical perspective within sports genetics emphasizes the interaction between an athlete's genetic makeup and environmental factors. Despite a strong genetic predisposition, the sports performance of an individual is influenced by several extrinsic factors including training intensity, nutritional practices, psychological conditioning, and socio-economic support (Puthucheary et al., 2011; Semenova, Hall & Ahmetov, 2023). This interaction underscores the complexity of athletic performance, where genetics sets the stage, but rigorous training and environmental inputs are necessary for realizing true performance potential (Ostrander et al., 2009; MacArthur & North, 2004). Consequently, a multidisciplinary approach encompassing genetic testing, advanced training analytics, and individualized coaching is imperative for maximizing performance outcomes.

Moreover, the study of sports genetics has broader implications for athlete management and talent identification. Early genetic screening could potentially help identify predispositions toward certain performance attributes, thereby informing coaches and sports organizations in their talent development strategies (Ahmetova et al., 2016; Rankinen et al., 2006). For example, individualized genetic profiles can guide decisions related to training focuses—a high endurance score might suggest long-distance running, while superior parameters in fast-twitch muscle function could align with sprint and power sports. However, a careful balance must be maintained to ensure that genetic information supplements rather than dictates athlete potential (Montgomery et al., 2002; Silva et al., 2024; Varillas-Delgado et al., 2022).

Despite the promising advances within sports genetics, the integration of gene-based interventions into practical sports medicine remains a challenge. Gene therapy, for example, initially honed for treating genetic disorders, has shown potential applications in enhancing tissue repair and recovery among athletes (Lamsam et al., 1998; ; Puthucheary). In this context, the transfer of therapeutic genes via viral or non-viral vectors can promote protein synthesis, which is crucial for cellular repair processes. However, clinical applications of gene therapy are complicated by the risks of unintended tissue targeting and the ethical considerations of gene doping, which could compromise the integrity of competitive sports (Miah, 2001; Williams et al., 2016).

Advances in genetic sciences over the past several decades have radically transformed our understanding of human physiology, athletic performance, and therapeutic interventions in sports medicine. The literature reveals that genetics plays a substantial role in determining not only an individual’s predisposition to certain physical activities but also their recovery from injuries and overall athletic performance (Stephan, 2012; Bouchard & Rankinen, 2001). Moreover, the emerging field of gene therapy promises new horizons in the treatment of sports-related injuries, offering innovative solutions to address conditions that have long challenged clinicians and athletes alike (Lamsam et al., 1998; Puthucheary et al., 2011.).

Gene therapy involves the transfer of genetic material into human cells to prevent or treat diseases caused by genetic abnormalities. This process leverages the delivery of a therapeutic gene to compensate for defects or deficiencies in a patient's genetic code, thereby normalizing protein synthesis that is crucial for cell function (Lamsam et al., 1998). The technique, which initially emerged in the context of treating inherited disorders, has now penetrated various domains of clinical research, including sports medicine and orthopedics. Innovative approaches are being used to repair tissues that traditionally exhibit limited intrinsic healing capacities, such as the meniscus, cartilage, and ligaments (Gerich et al., 1996; Puthucheary et al., 2011).

The potential applications of gene therapy in sports medicine extend far beyond simple tissue repair. Athletes often suffer from injuries that are exacerbated by inflammatory responses and poor vascularization. Traditional treatment modalities fail to provide long-lasting repair for certain soft tissue injuries, thereby creating an opportunity for gene-based interventions to promote regeneration and enhance healing processes (Martinek, 2000; Williams et al., 2016). The underlying principle of gene therapy is the introduction of specific genes into target cells, either as isolated units or in combination, to generate a sustained production of proteins that facilitate tissue repair (Semenova, Hall & Ahmetov, 2023). This process involves several complex steps, including transcription from DNA into heterogeneous nuclear RNA, subsequent mRNA processing, and the eventual translation of mRNA at ribosomes to form functional proteins (Huard et al., 2003).

The potential for genetic enhancement in sports must be viewed within a cautious framework. Gene doping, which involves the transfer of genetic material to augment performance, highlights the dual-edged nature of applying genetic research in sports settings (Hughes et al., 2011; Vlahovich et al., 2017). While gene therapy has opened avenues for treating sports injuries that typically exhibit poor healing capacity—such as meniscus tears, stress fractures, and nonunion fractures—it also raises serious questions regarding the fairness and long-term health implications for athletes (Pitsiladis et al., 2016; Puthucheary et al., 2011). Thus, sports genetics research should be seen primarily as a complementary tool aiding in personalized training rather than a definitive route to enhanced performance.

Ethical considerations continue to play a pivotal role in this rapidly evolving field. As genetic technologies advance, safeguarding athletes' rights and ensuring equitable access to genetic interventions become paramount challenges. The potential misuse of genetic information, through practices such as gene doping or discriminatory selection, poses a significant ethical dilemma that sports regulators and scientific communities must address (Miah, 2001; Williams et al., 2016). Establishing robust ethical frameworks is essential to balance innovation in sports genetics with the well-being and fair treatment of athletes (Ostrander et al., 2009; Vlahovich et al., 2017).

The ongoing integration of ethical guidelines and robust scientific methodologies will be essential in harnessing the full potential of sports genetics while ensuring that the pursuit of excellence remains equitable and safe for all athletes. Through continued research and responsible application of genetic findings, the future of athletic performance holds the promise of not only breaking performance barriers but also revolutionizing training and rehabilitation practices, ultimately redefining our understanding of human potential in sports (Pitsiladis et al., 2016; Williams et al., 2016).

Looking ahead, the future of sports genetics appears promising, with potential applications that extend from performance optimization to injury prevention and rehabilitation. The integration of genetic insights into sports science is expected to further catalyze the development of personalized training programs, which adapt to an individual's genetic predispositions and environmental exposures (Ahmetova et al., 2016; Pitsiladis et al., 2016). Such advancements not only enhance performance but also have the potential to minimize injury risks and accelerate recovery times, ultimately contributing to longer and healthier athletic careers (MacArthur & North, 2004; Hughes et al., 2011).

In conclusion, the intersection of genetics and sports performance represents a multifaceted field that combines principles of biology, medicine, and environmental science. While the ACE and ACTN3 genes have emerged as critical determinants of endurance and power, respectively, they are merely components of a larger and highly complex biological network that governs athletic performance (Montgomery et al., 2002; Puthucheary et al., 2011; Silva et al., 2024). The contemporary study of sports genetics, enriched by advances in molecular biology and gene mapping technologies, continues to highlight the importance of both genetic and environmental factors in shaping athletic talent. As researchers refine genetic screening methods and develop individualized training protocols, the promise of personalized sports medicine becomes increasingly attainable (Puthucheary et al., 2011).

In the realm of sports genetics, older studies laid the foundation by linking genetic markers to differences in muscle fiber composition and performance capabilities (Ahmetova et al., 2016; Bouchard & Rankinen, 2001). With the advent of high-throughput genomic techniques and advances in gene mapping, more precise correlations have been made between specific genetic variations and athletic performance. For instance, the discovery of performance-related genes such as ACE and ACTN3 has allowed for the characterization of athletes predisposed to either endurance-based or power-based activities (Ahmetova et al., 2016; Montgomery et al., 2002). Such findings underscore the dual influence of genetics and environmental factors—including training regimens, nutrition, and psychological factors—in determining athletic performance (Puthucheary et al., 2011; Semenova, Hall & Ahmetov, 2023).

Gene therapy, as a therapeutic intervention in sports medicine, shares similar ethical concerns. The possibility of using gene therapy for non-therapeutic enhancement of athletic performance—which could undermine the fairness of competitive sports—has raised considerable debate (Bouchard & Rankinen, 2001; Gerich et al., 1996). Early studies using viral vectors demonstrated the promise of gene transfer, yet also highlighted risks such as unintended tissue targeting and adverse immune responses (Lamsam et al., 1998) Consequently, regulatory bodies have imposed stringent guidelines for clinical applications of gene therapy, ensuring that it is used primarily for healing rather than enhancement (Martinek, 2000; Miah, 2001).

The evolution of gene therapy techniques—from viral-based vectors to advanced non-viral delivery systems—has been integral to the success of recent preclinical studies in sports medicine (Gerich et al., 1996; Huard et al., 2003). While clinical utilization of these methods for sports injuries remains in its infancy, preliminary evidence suggests that targeted gene delivery could significantly accelerate the healing processes in tissues that are otherwise slow to recover. For instance, the application of gene therapies for repairing ligament injuries or enhancing cartilage regeneration demonstrates a promising future for athletes who suffer from chronic or severe musculoskeletal conditions (Martinek, 2000; Semenova, Hall & Ahmetov, 2023).

Moreover, integrating gene therapy with modern regenerative medicine techniques, such as the use of stem cell therapies, opens further avenues for enhancing recovery outcomes. Combining the regenerative capacity of stem cells with gene therapy's ability to direct cell behavior provides a synergistic approach to tissue repair, potentially revolutionizing treatments for ACL tears, meniscus injuries, and other common sports-related trauma (Gerich et al., 1996; Huard et al., 2003). This integrative approach not only reinforces the structural repair of injured tissues but may also enhance their functional recovery, thereby reducing downtime and expediting a return to peak performance.

One of the most promising aspects of sports genetics is the idea that genetic analysis can inform personalized training regimens. Genetic tests that assess markers related to muscle efficiency, oxidative capacity, and recovery potential offer the prospect of tailoring training programs to individual needs (Stephan, 2012; Pitsiladis et al., 2016). For example, an athlete whose genetic analysis reveals superior muscle contraction efficiency may be more naturally suited for explosive power activities like sprinting. Conversely, an individual with markers indicating enhanced aerobic metabolism might excel in endurance sports (MacArthur & North, 2004; Rankinen et al., 2006). These insights can not only optimize performance but also help reduce injury risks by aligning training methods with inherent physiological capacities.

Despite these advances, the integration of genetic information into sports performance practices has not been without controversy. Critics argue that an overreliance on genetic predispositions might overshadow the essential role of rigorous training and environmental influences (Miah, 2001; Vlahovich et al., 2017). In addition, ethical questions arise regarding genetic privacy, the potential for gene doping, and discrimination based on genetic profiles (Pitsiladis et al., 2016). As such, while sports genetics offers transformative potential, its application in sports must be handled with caution and adherence to strict ethical standards.

The implications of sports genetics and gene therapy extend beyond individual athletes and have significant societal impacts as well. Enhanced understanding of genetic contributions to physiological performance can influence talent identification programs and improve the design of training regimens at both amateur and professional levels (Pitsiladis et al., 2016; MacArthur & North, 2004). In elite sports, where margins of victory are often razor-thin, knowledge of genetic predispositions may contribute to more informed decisions regarding athlete specialization and the development of long-term training strategies (Stephan, 2012; Rankinen et al., 2006).

Looking ahead, the continued evolution of gene therapy and genetic analysis promises to deepen our understanding of the biological foundations of athleticism. These advances lay the groundwork for tailored training regimens that are finely tuned to an athlete's genetic profile, as well as for regenerative therapies that restore function in previously intractable injuries. With careful application and ethical oversight, the integration of genetics into sports science could redefine the boundaries of human performance and enhance the overall quality of sports medicine in the 21st century (Huard et al., 2003; Pitsiladis et al., 2016).

Furthermore, considering the potential for gene doping, there is a pressing need to establish robust monitoring and regulatory mechanisms to prevent unethical practices. While gene therapy offers substantial benefits when implemented correctly, its misuse for performance enhancement could challenge ethical boundaries and disrupt the level playing field that is central to competitive sports (Vlahovich et al., 2017; Williams et al., 2016).

Comprehensive policies that address both medical and competitive concerns must be integrated into sports regulatory frameworks to ensure that advances in genetics are used solely for health and performance optimization, while upholding fairness and safety (Miah, 2001; Pitsiladis et al., 2016).

In summary, the literature on sports genetics and performance genes in sports portrays a field marked by rapid advancement and high clinical potential. Gene therapy, in particular, is emerging as a promising intervention for addressing soft tissue injuries and enhancing recovery, thereby fostering a closer integration between molecular genetics and sports medicine (Lamsam et al., 1998; Puthucheary et al., 2011). Simultaneously, the use of genetic analysis to understand predispositions to different athletic traits—such as muscle fiber composition and cardiovascular function—has refined our approach to training and talent identification (Ahmetova et al., 2016; Montgomery et al., 2010; Silva et al., 2024).

However, the advancement of these technologies also demands vigilance regarding ethical issues, including concerns over gene doping, privacy, and equitable access to these innovations (Miah, 2001). As such, ongoing research must strike a balance between the transformative potential of gene-based interventions and rigorous regulatory oversight and ethical considerations. The convergence of genetics and sports medicine represents not only a pathway to enhanced athletic performance but also a paradigm shift toward personalized approaches in sports training and injury rehabilitation (Bouchard & Rankinen, 2001; Martinek, 2000).

1.1 The potential role of ACE gene and ACTN3 gene on the sportive performance:

1.1.1 ACE (Angiotensin-Converting Enzyme)

The ACE gene holds a central role in regulating cardiovascular function, particularly in maintaining blood pressure and fluid balance. This gene encodes the angiotensin-converting enzyme, a crucial component of the renin-angiotensin system, which governs cardiovascular responses to various physiological demands, including exercise. Variations in the ACE gene have been shown to significantly influence athletic performance, especially in terms of endurance and cardiovascular efficiency.

One of the most extensively studied genetic variations in the ACE gene is the insertion/deletion (I/D) polymorphism, which results in three distinct genotypes: II, ID, and DD. Research has consistently highlighted the impact of these genotypes on athletic capabilities. The II genotype is often linked to enhanced endurance performance, making it more prevalent among elite endurance athletes. For instance, a study conducted by Yang et al. (2003) demonstrated that athletes excelling in prolonged aerobic activities were more likely to carry the II genotype, suggesting a genetic predisposition toward superior cardiovascular efficiency. Conversely, the DD genotype is commonly associated with advantages in strength and power-based sports, where short bursts of intense activity are required (Ma et al., 2013).

Beyond genetic predisposition, the ACE gene interacts dynamically with environmental factors such as training regimens and nutrition. Athletes with the II genotype tend to respond more favorably to endurance-focused training, exhibiting greater improvements in aerobic capacity and overall performance. This gene-environment interplay underscores the importance of adopting personalized training strategies tailored to an athlete's genetic profile. By leveraging this information, coaches and athletes can maximize performance potential and achieve more targeted outcomes (Oral & Ojo, 2025)

The influence of the ACE gene extends beyond endurance performance to recovery and adaptation processes. Variations in this gene can affect the rate at which athletes recover from intense physical exertion, thereby impacting their training frequency and long-term performance trajectory. For example, individuals with certain genotypes may experience faster recovery times, enabling them to sustain higher training loads and improve consistently. Understanding these genetic factors provides valuable insights for optimizing training plans and managing recovery, ultimately enhancing athletic success.

In summary, the ACE gene plays a multifaceted role in athletic performance, influencing endurance, recovery, and adaptation. Its interaction with environmental factors highlights the potential for personalized approaches in training and nutrition. By integrating genetic insights with tailored strategies, athletes can unlock their full potential and achieve superior results in their respective disciplines.

1.1.2 *ACTN3 (Alpha-Actinin-3)*

The ACTN3 gene encodes for a protein called alpha-actinin-3, which is predominantly expressed in fast-twitch muscle fibers, also known as type II fibers. These fibers are essential for activities requiring short bursts of power and speed, such as sprinting, jumping, or weightlifting. The presence of the ACTN3 protein is strongly associated with enhanced muscle contraction and explosive strength, making it a critical factor in sports that demand high-intensity performance (Pimenta et al., 2013)

A key genetic variation within the ACTN3 gene, known as the R577X polymorphism, has been extensively studied for its impact on athletic capabilities. This polymorphism results in two distinct alleles: the R allele, which produces a functional alpha-actinin-3 protein, and the X allele, which leads to a non-functional version of the protein. Individuals can inherit one of three possible genotypes: RR (two R alleles), RX (one R and one X allele), or XX (two X alleles). Those with at least one R allele (RR or RX) are more likely to excel in power-oriented sports due to their ability to produce the functional protein, which enhances muscle performance. In contrast, individuals with the XX genotype, lacking functional alpha-actinin-3, may have a natural predisposition toward endurance-based activities, as their muscle fibers adapt differently (Ruiz et al., 2010; Tharabenjasin et al., 2019)

Research has consistently highlighted the influence of this genetic variation on athletic performance. For example, a seminal study by MacArthur and North in 2004 revealed that elite sprinters and power athletes tend to have a significantly higher frequency of the R allele compared to endurance athletes. This finding underscores the role of genetics in determining an athlete's suitability for specific types of sports and has profound implications for talent identification and training optimization. By understanding an athlete’s genetic profile, coaches and sports scientists can design personalized training programs that align with their natural strengths, thereby maximizing their potential.

Beyond its role in performance, ACTN3 also influences muscle recovery and adaptation to training. Athletes with the R allele may experience more efficient muscle repair and adaptation following intense exercise, allowing them to recover faster and improve over time. This further emphasizes the importance of integrating genetic insights into the development of tailored training regimens (Baltazar-Martins et al., 2020)

In conclusion, both ACTN3 and ACE are pivotal genes that influence athletic performance through their roles in muscle composition and cardiovascular function, respectively. The ACTN3 gene plays a pivotal role in shaping athletic performance, particularly in power and speed-based sports. As the field of sports genetics continues to evolve, understanding the impact of genes like ACTN3 can revolutionize training strategies and help athletes reach new heights in their performance. The ACE gene plays a multifaceted role in athletic performance, influencing endurance, recovery, and adaptation. Its interaction with environmental factors highlights the potential for personalized approaches in training and nutrition. By integrating genetic insights with tailored strategies, athletes can unlock their full potential and achieve superior results in their respective disciplines.

While both ACTN3 and ACE are known as the basic genes affecting athletic performance, many more candidate sports genes have been revealed as a result of research on sports genes in recent years; and the activities of these genes on sports performance and exercise physiology are being examined in detail.

1. MSTN (Myostatin) Gene The MSTN gene encodes myostatin, a protein that inhibits muscle growth. Variants in this gene can lead to increased muscle mass and strength. Research has shown that the mutations in the MSTN gene may have a natural advantage in strength-based sports due to reduced myostatin activity, allowing for greater muscle hypertrophy (Lee, 2004; McPherron & Lee, 2002).

2. PPARA (Peroxisome Proliferator-Activated Receptor Alpha) Gene The PPARA gene is involved in the regulation of fatty acid metabolism and energy homeostasis. Variants in this gene are associated with endurance performance, as they influence the body's ability to utilize fat as an energy source during prolonged exercise (Horowitz et al., 2010; Manickam & Wahli, 2017). Athletes with certain PPARA genotypes may exhibit enhanced endurance capabilities.

3. BDNF (Brain-Derived Neurotrophic Factor) Gene The BDNF gene is critical for neuroplasticity and brain function. Variants in BDNF have been linked to cognitive performance and response to training, influencing mental resilience and recovery in athletes. Some studies suggest that specific BDNF alleles may contribute to improved performance in sports requiring strategic thinking and quick decision-making (Moreno-Infantes et al., 2024).

4. CYP19A1 (Aromatase) Gene The CYP19A1 gene encodes the aromatase enzyme, which converts androgens into estrogens. Variants in this gene can affect hormonal balance and subsequently influence muscle mass and recovery rates. Research indicates that athletes with specific CYP19A1 polymorphisms may experience distinct adaptations in response to training (Kumagai et al., 2022; Kumagai et al., 2023).

5. COL5A1 (Collagen Type V Alpha 1 Chain) Gene The COL5A1 gene is involved in the formation of collagen, which is crucial for connective tissue integrity. Variants in this gene have been associated with an increased risk of injuries, particularly tendon injuries, in athletes. Understanding COL5A1 polymorphisms can help in developing injury prevention strategies (Posthumus et al., 2009).

The understanding of these genetic factors not only aids in talent identification but also allows for the development of tailored training programs, which can significantly enhance athletic performance. As research continues to uncover the complex interplay between genetics and sports, it becomes increasingly clear that a personalized approach to training and performance optimization is essential for maximizing an athlete's potential.

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Chapter 2

An Overview of the Fundamentals of Ergogenic Support and Sport Nutrition

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1. The Basic Overview of Ergogenic Support

Ergogenic aids represent a complex arsenal of interventions designed to enhance human physical performance beyond innate physiological limits. This review explores the multifaceted landscape of ergogenic support encompassing nutritional, pharmacological, physiological, mechanical, and psychological domains. Through systematic analysis of current literature, this review evaluates the efficacy, safety, and ethical issues surrounding ergogenic aids in athletic performance, and key findings in this area suggest that evidence-based nutritional ergogenics, such as creatine monohydrate, β-alanine, caffeine, and dietary nitrates, can provide modest but significant performance improvements (2–15%) within acceptable safety parameters. In contrast, pharmacological agents such as anabolic-androgenic steroids and selective androgen receptor modulators offer significant performance gains but should not be overlooked as carrying significant health risks and ethical violations. The emergence of precision sports nutrition integrating genomic profiling and metabolomic analysis should highlight the critical importance of balancing performance optimization with athlete health and competitive integrity, with a paradigm shift toward individualized supplementation strategies.

Ergogenic aids—conceptually defined as exogenous applications or substances engineered to potentiate energy utilization, metabolic production, or physiological recovery—constitute indispensable elements within contemporary athletic paradigms, spanning both training methodologies and competitive frameworks (Smith & Jones, 1985). This heterogeneous classification

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encompasses multifaceted interventions ranging from macronutrient supplementation (e.g., creatine compounds to augment phosphagen reserves, protein isolates supporting myofibrillar hypertrophy) to micronutrient formulations delivering essential vitamins and minerals that cofactorize enzymatic pathways critical to energy transduction. Concurrently, widely adopted modalities include caffeine-infused beverages acting via adenosine-receptor antagonism to enhance neuromuscular excitation, carbohydrate-dense gels optimizing glycogen sparing during prolonged exertion, and biomechanically sophisticated apparatus such as compression textiles augmenting venous return and engineered footwear improving elastic energy restitution during ground contact—each garnering substantial scholarly and practical attention within the ergogenic domain (Lippi & Banfi, 2012; Thomas, Bishop, & Lees, 2016). Beyond their primary function of augmenting quantifiable performance metrics—including muscular strength, anaerobic power, aerobic capacity, and recuperative efficiency—these aids confer secondary physiological advantages. Such benefits manifest through the preservation of hydro-electrolytic equilibrium during thermoregulatory stress, attenuation of exercise-induced oxidative stress via Nrf2 pathway modulation, and optimization of substrate metabolism during sustained physical exertion through AMPK-mediated glucose uptake (Bailey et al., 2010; Phillips, 2014).

Empirical investigations conducted across four decades have unequivocally established the efficacy of ergogenic interventions, with documented performance enhancements oscillating between marginal (2%–5%) and substantial (10%–15%) increments. These differential outcomes are contingent upon sport-specific biodynamic demands, competitive echelon, and inter-individual neurophysiological sensitivity—a phenomenon extensively characterized in both laboratory-controlled trials and ecological validations (Greenhaff, 1998; Guest et al., 2014). For instance, creatine monohydrate administration elevates repeated sprint performance by approximately 15% among team-sport athletes through accelerated phosphocreatine resynthesis kinetics, while dietary nitrate supplementation—exemplified by beetroot juice—enhances time-trial efficiency by 5%–8% in elite cyclists via nitrite-to-nitric oxide conversion improving mitochondrial oxygen utilization (Jones, 2014). Although such improvements may appear statistically modest in isolation, their practical significance becomes decisive in elite competitions, where outcomes are frequently determined by temporal differentials measured in centiseconds or singular point advantages—margins often eclipsing natural biological variance among competitors.

Notwithstanding their ergonomic utility, these aids remain enmeshed in multifaceted controversy. Paramount among concerns are safety implications, particularly regarding pharmacological agents such as selective androgen receptor modulators (SARMs) or supraphysiological stimulant dosages, which may precipitate endocrine dysregulation, cardiovascular perturbations (including hypertension and ventricular hypertrophy), and adverse neuropsychiatric sequelae ranging from anxiety to dependency syndromes (Lippi & Banfi, 2012; World Anti-Doping Agency, 2021). Even ostensibly benign nutritional supplements pose iatrogenic risks; caffeine consumption exceeding 9 $mg \cdot kg^{-1}$ body mass may induce tachyarrhythmias, gastrointestinal distress, and circadian disruption—manifestations anticipated to detrimentally affect both physiological well-being and athletic output, particularly during multi-stage competitions requiring sustained vigilance (Guest et al., 2014). Ethical considerations further complicate this landscape, as the demarcation between permissible performance optimization and prohibited doping practices becomes nebulous when athletes utilize substances possessing substantial ergogenic properties yet residing within regulatory lacunae—a challenge exemplified by prohormones and peptide hormones lacking reliable detection assays (Petróczi & Naughton, 2008). The World Anti-Doping Agency (WADA) addresses these challenges through annually updated Prohibited Lists incorporating emerging pharmacological threats and mandatory athlete education initiatives promoting pharmacological literacy (World Anti-Doping Agency, 2021). Nevertheless, heterogeneous enforcement protocols across national federations perpetuate jurisdictional inconsistencies, undermining global harmonization in anti-doping governance and creating asymmetries in sanction severity for identical infractions (WADA, 2021).

Contemporary meta-analyses underscore profound inter-individual variability in ergogenic responsiveness, attributable to polygenic, nutritional, and microbiological determinants that modulate intervention efficacy at population and individual levels (Guest et al., 2014; Jones et al., 2017). Polymorphisms within loci such as the creatine transporter gene (SLC6A8) or carnosine synthase (CARNS1) significantly modulate the pharmacokinetics of creatine uptake and β-alanine-mediated carnosine synthesis, respectively—with non-responder phenotypes exhibiting allele frequencies exceeding 25% in certain cohorts (Jones et al., 2017). Concomitantly, baseline nutritional status (e.g., iron-deficient athletes showing blunted nitrate efficacy), enteric microbial ecology governing short-chain fatty acid production, and cumulative training exposure collectively influence intervention outcomes through epigenetic modifications altering gene expression profiles. Athletes exhibiting suboptimal intramuscular phosphocreatine reserves, for example, derive superior benefits from creatine loading protocols compared to counterparts with saturated phosphagen stores, achieving performance differentials exceeding 12% in power-output metrics (Greenhaff, 1998). Consequently, the integration of ergogenic aids necessitates personalized frameworks reconciling performance objectives with bioethical imperatives—requiring multidisciplinary collaboration among sports physiologists, genetic counselors, and anti-doping specialists to ensure both athlete safeguarding and competitive integrity across evolving pharmacological landscapes.

1.1 Nutritional Ergogenic Aids

Nutritional ergogenic aids have garnered extensive scientific attention due to their favorable safety profiles and regulatory acceptance, positioning them as indispensable tools within evidence-based athletic development frameworks. Among the most rigorously studied compounds, creatine monohydrate emerged as a foundational supplement following seminal research demonstrating its capacity to increase intramuscular phosphocreatine stores by 10-30% (Greenhaff, 1997). This biochemical augmentation facilitates rapid adenosine triphosphate (ATP) regeneration during explosive efforts through the enzymatic catalysis of creatine kinase, thereby translating to measurable improvements in repeated-sprint performance and maximal power output across disciplines requiring instantaneous force production—from weightlifting to rugby scrum engagements. The mechanistic elegance of this intervention lies in its optimization of the phosphagen energy system, which dominates high-intensity efforts lasting ≤30 seconds, effectively delaying the onset of neuromuscular fatigue through enhanced substrate availability within type II muscle fibers.

β-Alanine supplementation represents another well-characterized nutritional intervention operating via distinct physiological pathways. Chronic supplementation protocols (4-6 $g \cdot day^{-1}$ administered over 4-8 weeks) elevate skeletal muscle carnosine concentrations by 40-80% through β-alanine-dependent dipeptide synthesis, substantially enhancing the myocyte's buffering capacity against exercise-induced acidosis (Harris et al., 2006). This proton sequestration mechanism proves particularly efficacious during high-intensity efforts lasting 60-240 seconds—a critical window where hydrogen ion accumulation typically impairs contractile function—yielding performance advantages in disciplines such as 800-meter track events, 200-meter swimming competitions, and 4-kilometer cycling time trials. Importantly, carnosine's multifaceted role extends beyond pH regulation, encompassing antioxidant functions and calcium sensitivity modulation, thereby providing complementary ergogenic benefits rarely captured in isolated performance metrics.

Caffeine's ergogenic properties stem primarily from its role as a non-selective adenosine receptor antagonist within the central nervous system. Pre-exercise administration of 3-6 $mg \cdot kg^{-1}$ body mass enhances cortical arousal through noradrenergic activation, reduces perceived exertion via altered sensory processing in the anterior cingulate cortex, and improves both endurance and power performance metrics by 2-6% across diverse athletic populations (Grgic et al., 2018). The compound's rapid absorption kinetics—with peak plasma concentrations occurring 30-60 minutes post-ingestion—enable strategic temporal alignment with competitive events, while its lipophilic nature facilitates efficient blood-brain barrier penetration. Contemporary applications extend beyond traditional anhydrous caffeine to include novel delivery systems such as caffeine-carbohydrate hydrogels and mucoadhesive buccal patches, which optimize bioavailability while minimizing gastrointestinal discomfort during prolonged exertion.

Dietary nitrates, primarily sourced from beetroot juice (Beta vulgaris rubra) and leafy green vegetables, undergo sequential enterosalivary bioconversion to nitrite and nitric oxide (NO) through symbiotic bacterial nitrate reductases. This endogenous NO production promotes smooth muscle vasodilation, enhances mitochondrial efficiency through cytochrome c oxidase modulation, and reduces the oxygen cost of submaximal exercise (i.e., improved mechanical efficiency), collectively resulting in improved time-to-exhaustion by 5-15% across environmental conditions ranging from normoxia to hypoxic altitudes (Jones, 2014). The paradoxical nature of this intervention—whereby a seemingly inert anion confers substantial ergogenic benefits—exemplifies the sophisticated interplay between nutritional biochemistry and exercise physiology that characterizes modern sports science.

The emergence of precision sports nutrition has revolutionized supplementation paradigms by incorporating polygenic, metabolic, and phenotypical characteristics into individualized protocols. Genetic polymorphisms significantly modulate ergogenic responsiveness; for instance, ACTN3 R577X variants influence type IIx fiber distribution and subsequent creatine transport efficiency, while CYP1A2 polymorphisms (particularly rs762551) determine hepatic caffeine clearance rates through cytochrome P450 pathway alterations (Guest et al., 2014). Such pharmacogenomic insights enable practitioners to stratify athletes into responder cohorts using combinatorial genetic panels, thereby optimizing intervention efficacy while circumventing adverse effects in genetically susceptible individuals—a paradigm shift from population-based to personalized nutritional frameworks.

2. Pharmacological and Hormonal Agents in Athletic Performance

Pharmacological ergogenic aids occupy a uniquely controversial position within sports performance enhancement paradigms, offering substantial physiological advantages while simultaneously introducing profound ethical dilemmas and multisystemic health risks. These compounds—spanning synthetic hormones, receptor modulators, and metabolic activators—function through targeted interference with endogenous signaling pathways, yielding ergogenic benefits that often exceed 10–25% beyond natural physiological limits. The tension between their potent performance-enhancing capabilities and severe iatrogenic consequences underscores a complex medico-ethical landscape where pharmacological innovation perpetually challenges regulatory frameworks designed to preserve competitive integrity.

2.1 Anabolic-Androgenic Steroids (AAS)

Anabolic-androgenic steroids represent the prototypical class of prohibited substances, initially synthesized during the 1930s for clinical management of hypogonadism and muscle-wasting pathologies but later co-opted into athletic contexts due to their profound hypertrophic effects. These synthetic testosterone derivatives exert their mechanistic influence through high-affinity binding to cytosolic androgen receptors, which subsequently undergo nuclear translocation and dimerization to modulate transcriptional activity across thousands of genes governing myofibrillar protein synthesis, satellite cell proliferation, and extracellular matrix remodeling (Hartgens & Kuipers, 2004). Controlled trials involving healthy individuals demonstrate that supraphysiological dosing regimens (typically 5–10× endogenous production) administered over 10–20 weeks yield lean mass accretion of 10–20% alongside proportional strength increases—improvements most pronounced during resistance training periods due to synergistic upregulation of mTOR signaling pathways and enhanced ribosomal biogenesis.

The deleterious multisystemic consequences of AAS misuse, however, present a stark counterpoint to their ergogenic efficacy. Hepatotoxicity manifests through diverse pathologies including peliosis hepatis (blood-filled cystic formations), cholestatic jaundice from disrupted bile acid transport, and hepatocellular carcinoma linked to 17α-alkylated compounds that resist first-pass metabolism. Cardiovascular sequelae are equally concerning, with longitudinal studies documenting left ventricular hypertrophy exceeding 15% mass increase, impaired diastolic filling dynamics, and pro-atherogenic lipid profiles characterized by 30–60% reductions in HDL cholesterol alongside elevated LDL oxidation (Baggish et al., 2017). Endocrine disruption involves profound suppression of the hypothalamic-pituitary-gonadal axis via negative feedback inhibition, resulting in testicular atrophy with reduced spermatogenesis, persistent hypogonadism lasting ≥12 months post-cessation, and paradoxical estrogenic effects from peripheral aromatization including gynecomastia. Neuropsychiatric manifestations—colloquially termed "roid rage"—reflect GABAergic inhibition and serotonergic dysregulation within limbic structures, clinically presenting as heightened aggression, affective lability, and in severe cases, psychotic episodes with paranoid ideation requiring neuroleptic intervention.

2.2 Selective Androgen Receptor Modulators (SARMs)

Selective androgen receptor modulators emerged as pharmaceutical innovations designed to circumvent the non-selective toxicity of traditional AAS by exploiting tissue-specific receptor conformational changes. Compounds such as ostarine (MK-2866) and ligandrol (LGD-4033) achieve preferential anabolic activation in musculoskeletal tissues through recruitment of distinct coactivator complexes while sparing prostate and hepatic systems due to differential corepressor binding affinities (Dalton et al., 2011). Early phase human trials documented lean mass increases of 1–3 kg following 8–12 weeks of administration—approximately 40–60% of AAS efficacy but with minimal alterations in prostate-specific antigen or hepatic transaminases. This tissue selectivity initially positioned SARMs as promising therapeutic agents for cancer cachexia and osteoporosis.

Emerging clinical surveillance, however, reveals concerning safety profiles that undermine their therapeutic promise. A recent longitudinal cohort study of 68 recreational SARM users identified electrocardiographic abnormalities in 22% of participants, including clinically significant QT-interval prolongation (>500 ms) predisposing to torsades de pointes arrhythmias during exercise-induced catecholamine surges (Christiansen et al., 2020). Additional investigations suggest potential endocrine disruption through suppression of gonadotropin-releasing hormone pulsatility and dysregulation of thyroid hormone conversion pathways. The regulatory landscape surrounding SARMs remains fraught with ambiguity, as many compounds exist in legal gray areas—marketed as "research chemicals" while simultaneously appearing on the World Anti-Doping Agency's (WADA) Prohibited List. This jurisdictional complexity severely impedes enforcement efforts and creates dangerous informational vacuums where athletes access inadequately characterized substances through unregulated online markets without proper toxicological assessment.

2.3 Ethical and Legal Considerations

The deployment of pharmacological ergogenics fundamentally violates the principle of fair opportunity that underpins competitive sport—a social contract requiring that outcomes reflect natural talent and dedicated training rather than biochemical manipulation. Beyond conferring disproportionate performance advantages, these substances generate coercive environments where clean athletes face psychological pressure to engage in hazardous practices merely to remain competitive, effectively transforming sports into pharmacological arms races. WADA's Prohibited List embodies a science-based approach to preserving competitive integrity while safeguarding athlete welfare, annually updating substance classifications through evidence-based evaluation of performance enhancement potential, health risks, and ethical violations.

Contemporary anti-doping methodologies employ increasingly sophisticated analytical techniques to detect both established and emerging compounds. Isotope ratio mass spectrometry identifies synthetic testosterone through carbon-13 depletion patterns, while athlete biological passports establish longitudinal hematological and steroidal profiles to detect physiological deviations indicative of doping. Despite these advances, a perpetual innovation gap exists where novel designer compounds (e.g., selective estrogen receptor modulators, myostatin inhibitors) typically enter athletic use 12–24 months before detection protocols become available. This cat-and-mouse dynamic necessitates sustained investment in forensic toxicology research and international intelligence sharing to identify emerging threats. Equally critical are educational initiatives addressing the "pharmacological literacy gap" among adolescent athletes, who often underestimate compound-specific risks while overestimating ergogenic benefits due to online misinformation ecosystems.

3. The Impact of Ergogenic Support on Athletes' Overall Health

Ergogenic interventions extend their physiological influence far beyond immediate performance metrics, embedding themselves within complex biological systems governing long-term athlete well-being. This intricate interplay between performance enhancement and systemic health demands rigorous scientific scrutiny, particularly as ergogenic aids evolve from peripheral supplements to central components of athletic preparation. The following analysis examines these multifaceted health implications through a dual lens:

acknowledging validated therapeutic potentials while critically evaluating underexplored iatrogenic risks across physiological domains.

Nutritional ergogenics demonstrate unexpected pleiotropic benefits transcending their primary performance-enhancing roles, revealing significant therapeutic potential in clinical contexts. Creatine monohydrate, for instance, not only augments high-intensity exercise capacity but also exerts neuroprotective effects through multifaceted mechanisms. Enhanced cerebral phosphocreatine reserves stabilize neuronal energy dynamics during metabolic stress, while upregulated endogenous antioxidant pathways mitigate oxidative damage in hippocampal and cortical microstructures (Avgerinos et al., 2018). These neurochemical adaptations support emerging applications in neurodegenerative pathologies—including Parkinsonian symptom management and post-concussion rehabilitation—where creatine-mediated mitochondrial biogenesis counteracts progressive synaptic dysfunction.

Concurrently, β-Alanine extends its physiological significance beyond intramuscular pH modulation. Chronic elevation of muscle carnosine concentrations confers potent antioxidant properties through direct scavenging of reactive oxygen species and inhibition of advanced glycation end-product formation. Such redox modulation preserves contractile protein integrity during exhaustive exertion and demonstrates promise for populations with impaired oxidative homeostasis, particularly type 2 diabetics experiencing accelerated muscle catabolism. The dipeptide's unique buffering characteristics may further benefit individuals with inherited metabolic disorders characterized by systemic acidosis, especially where conventional alkalinizing agents prove insufficient.

Dietary nitrate supplementation initiates equally compelling cardioprotective adaptations mediated through enterosalivary nitric oxide metabolism. Nitric oxide-dependent vasodilation enhances endothelial function by upregulating cyclic guanosine monophosphate signaling pathways, yielding sustained blood pressure reductions exceeding 5–10 mmHg in hypertensive cohorts. These hemodynamic improvements correlate strongly with enhanced vascular compliance and reduced arterial stiffness—established biomarkers associated with attenuated cardiovascular disease risk throughout the human lifespan. Notably, such benefits manifest irrespective of athletic status, positioning nitrate-rich botanicals as viable adjuvants within primary prevention frameworks.

Despite favorable safety profiles among well-researched ergogenics, substantial toxicological concerns persist within the unregulated supplement ecosystem. Quality control failures remain endemic, with independent chromatographic analyses routinely detecting undeclared pharmacoactive contaminants—including anabolic prohormones, β_2-agonists, and central nervous system stimulants—in 12–28% of commercial products (Maughan et al., 2018). Heavy metal contamination from inadequately purified botanical extracts presents additional carcinogenic risks, necessitating stringent third-party verification through programs like NSF International's Certified for Sport®.

Exercise-induced hyperthermia represents a critical physiological challenge where ergogenic interventions exert paradoxical effects on thermoregulatory efficiency. Creatine's osmotic properties enhance intracellular hydration by 12–15%, effectively expanding the body's fluid reservoir available for evaporative cooling. This cellular volumizing effect prolongs time to exhaustion in hot environments (35–40°C) by delaying the critical core temperature threshold (≈39.5°C) where central nervous system-mediated fatigue mechanisms activate (Lopez et al., 2009). Field studies confirm 23% greater sweat production capacity during repeated sprints in humid conditions, though this advantage diminishes without concomitant fluid replacement strategies.

4. The Impact of Ergogenic Support on Athletic Performance

The strategic deployment of ergogenic aids manifests profound discipline-specific variations, reflecting the intricate interplay between physiological demands and performance objectives across athletic domains. This critical analysis examines evidence-based implementation protocols through three interconnected dimensions: strength/power sports demanding explosive force production, endurance activities requiring sustained metabolic efficiency, and recovery optimization essential for adaptation continuity. Contemporary sports science now recognizes these interventions not merely as performance adjuncts but as integral components of periodized training architectures, necessitating sport-specific pharmacokinetic and dose-response considerations.

4.1 *Strength and Power Sports*

Explosive disciplines including Olympic weightlifting, sprint athletics, and vertical jump competitions impose extreme demands on the phosphagen energy system, necessitating rapid adenosine triphosphate regeneration within type IIx muscle fibers. Creatine monohydrate persists as the preeminent ergogenic compound for these endeavors, with comprehensive meta-analyses confirming 5–15% improvements in peak power output, 10–20% increases in total work capacity during repeated maximal efforts, and significantly augmented training volume tolerance (Kreider et al., 2017). The underlying mechanisms involve not only phosphocreatine resynthesis acceleration but also myogenic satellite cell proliferation and glycogen supercompensation within fast-twitch motor units.

Optimal creatine protocols incorporate a biphasic dosing strategy: an initial loading phase employing either 20 $g \cdot day^{-1}$ distributed across four daily administrations for 5–7 days or weight-adjusted loading at 0.3 $g \cdot kg^{-1}$ for 5 days achieves near-complete intramuscular saturation. Subsequent maintenance dosing of 3–5 $g \cdot day^{-1}$ sustains ergogenic benefits while circumventing gastrointestinal complications and minimizing extracellular fluid retention that could impair power-to-mass ratios. Complementary nutritional strategies feature leucine-enriched whey protein supplementation timed within the post-exercise anabolic window, delivering 2.5–3 g leucine per serving to maximally stimulate mammalian target of rapamycin (mTOR) phosphorylation and downstream protein translation machinery (Phillips & Van Loon, 2011).

β-Alanine supplementation demonstrates particular efficacy in power sports involving repeated high-intensity bouts with limited recovery intervals, notably track cycling pursuits, rowing events, and 800-meter running disciplines. By elevating intramuscular carnosine concentrations by 40–60% following 4–6 weeks of daily 4–6 g dosing, athletes gain enhanced hydrogen ion buffering capacity during efforts lasting 60–240 seconds. This biochemical adaptation delays the critical pH threshold (≈6.5) where glycolytic enzyme inhibition and calcium sensitivity impairment precipitate fatigue, thereby preserving force production during terminal exertion phases.

4.2 *Endurance Sports*

Prolonged endurance activities present multifaceted physiological challenges spanning substrate mobilization, oxygen utilization efficiency, and neuromuscular fatigue resistance. Contemporary ergogenic approaches consequently target distinct metabolic bottlenecks through complementary biochemical pathways. Carbohydrate supplementation remains foundational, with current evidence supporting ingestion rates of 30–60 $g \cdot h^{-1}$ during events of 1–2.5 hours duration and up to 90 $g \cdot h^{-1}$ for ultra-endurance competitions exceeding 2.5 hours (Stellingwerff & Cox, 2014). The utilization of multiple transportable carbohydrates—specifically glucose:fructose mixtures in 2:1 ratios—exploits independent intestinal transporters (SGLT1 and GLUT5) to maximize absorption kinetics while minimizing gastrointestinal distress that commonly plagues endurance athletes.

Caffeine's ergogenic properties for endurance performance derive from dual central and peripheral mechanisms. At optimal doses of 3–6 $mg \cdot kg^{-1}$ consumed 30–60 minutes pre-exercise, adenosine receptor antagonism reduces perceived exertion and enhances motor unit recruitment motivation, while concomitant elevations in intramuscular calcium release potentiate contractile efficiency.

Enhanced free fatty acid mobilization further spares glycogen reserves during submaximal intensities, particularly in athletes with impaired fat oxidation phenotypes.

Dietary nitrate supplementation offers unique advantages through nitric oxide-mediated improvements in mitochondrial efficiency. Standardized protocols delivering 6–8 mmol nitrate (typically via 70–140 mL beetroot juice) 2–3 hours pre-exercise reduce oxygen consumption at given workloads by 3–5% through attenuated proton leakage and improved electron transport chain coupling. This metabolic efficiency translates directly to delayed fatigue onset during time-trial efforts and enhanced tolerance for threshold-intensity training.

4.3 *Recovery Optimization*

Post-exercise recovery is a critical determinant of long-term athletic development, with nutritional interventions profoundly affecting recovery kinetics across multiple physiological systems (Jäger et al., 2017; Schoenfeld et al., 2013). Protein intake immediately post-exercise (20–25 g high-biovalue protein or 0.25 g kg^{-1} body mass) has been shown to stimulate maximal muscle protein synthesis rates via essential amino acid supply, particularly leucine-mediated mTORC1 activation (Jäger et al., 2017). Delayed gastric emptying of casein protein provides sustained aminoacidemia during overnight recovery, reduces proteolysis, and has been found to promote net positive nitrogen balance (Tipton et al., 2004).

Phytochemical interventions hold significant promise in modulating exercise-induced inflammation (D'Andrea, 2020). Cherry concentrate (providing 100–120 mg anthocyanins daily) suppresses cyclooxygenase-2 activity and interleukin-6 production after eccentric exercise (Howatson et al., 2010), while standardized curcumin formulations (1–3 g day^{-1} with piperine) have been implicated in their ability to inhibit nuclear factor kappa-B signaling cascades (D'Andrea, 2020). These accelerate functional recovery but require strategic timing to avoid blunting inflammatory signaling necessary for adaptation.

Sleep architecture profoundly influences neuroendocrine recovery pathways, and certain ergogenic compounds are known to exert chronobiological effects. Caffeine antagonism of adenosine persists for 6+ hours and has been found to potentially reduce slow-wave sleep duration when consumed before bed (Suh et al., 2021). In contrast, magnesium bisglycinate (200–400 mg) increases gamma-aminobutyric acid receptor sensitivity and can promote sleep onset (Gottesmann, 2002), while L-theanine (100–200 mg) has been shown to increase alpha brain wave activity associated with relaxation without sedation (Suh et al., 2021).

4.4 *Future Directions and Emerging Technologies*

The frontier of ergogenic science undergoes continuous metamorphosis, propelled by synergistic advances across molecular biology, precision medicine, and biosensor innovation. This dynamic convergence heralds a transformative epoch where athletic performance optimization transcends traditional supplementation paradigms, evolving toward integrative bio-digital frameworks. Emerging technological vectors promise unprecedented capabilities in predictive analytics, personalized intervention design, and real-time physiological modulation, fundamentally redefining athlete-support systems interactions.

Contemporary athletic nutrition transitions toward hyper-personalization through genomic profiling, with polymorphic variations in key genes serving as predictive biomarkers for ergogenic response stratification. ACTN3 R577X allelic variants differentially regulate fast-twitch fiber hypertrophy potential, while ACE I/D polymorphisms influence angiotensin-converting enzyme activity and thereby cardiovascular adaptation kinetics. CYP1A2 genotyping further enables caffeine metabolism profiling, identifying "slow metabolizers" susceptible to adverse cardiovascular effects at standard dosages (Pickering & Kiely, 2017). Such genetic architecture, when integrated with phenotypic biomarkers and longitudinal training data, facilitates truly individualized supplementation protocols calibrated to expression pathways.

Ergogenic support systems constitute sophisticated bioenhancement tools requiring judicious application across efficacy, safety, and ethical dimensions. Evidence-based nutritional agents—including creatine's phosphagen system optimization, β-alanine's acid-buffering enhancement, caffeine's central fatigue modulation, and dietary nitrates' metabolic efficiency amplification—deliver significant performance benefits within established risk parameters. Conversely, pharmacological agents like anabolic-androgenic steroids produce profound gains at the cost of multisystem toxicity and fundamental violations of sport's ethical contract.

Future advancements will increasingly pivot toward precision ergogenesis, integrating genomic predispositions, real-time biomarker feedback, and machine learning algorithms to create dynamic supplementation architectures. This paradigm shift promises unprecedented individualization but simultaneously amplifies regulatory challenges, particularly regarding gene-editing technologies and neuroenhancement vectors currently undetectable through conventional anti-doping methodologies.

Optimal ergogenic integration demands multidisciplinary collaboration across exercise physiologists, nutritional biochemists, sports physicians, and ethical oversight committees. Athlete education remains paramount, empowering informed decision-making through comprehensive understanding of mechanistic pathways, dose-response relationships, and potential adverse effect profiles. Digital learning platforms now deliver interactive pharmacokinetic modules and virtual reality simulations of prohibited substance consequences, significantly enhancing knowledge retention.

Ultimately, the telos of ergogenic science resides in safely unlocking human performance potential while preserving competitive integrity. By maintaining uncompromising scientific rigor, prioritizing longitudinal athlete health surveillance, and embedding ethical considerations within technological development, the sports community can navigate the evolving ergogenic landscape without compromising the essential values that render athletic achievement meaningful.

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Chapter 3

Kinesiophobia and Sport

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Definition of Pain

The International Association for the Study of Pain (IASP) defines pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage" (Raja et al., 2020). Pain is a multidimensional construct that encompasses cognitive, sensory, and affective components (Reddan & Wager, 2019). The definition and underlying components of pain indicate that it is an inherently subjective experience. Moreover, pain can be influenced by various factors such as age, gender, level of education, and social and cultural context (Öngel, 2017).

Classification of Pain

Pain can be influenced by a variety of factors; therefore, it can be examined through different classification approaches.

Pain Classification by Duration

Table 1. Classification of Pain According to Duration

Acute Pain	• Acute pain typically emerges when tissue damage occurs. • When the injured area heals, the pain completely subsides (Raja et al., 2020).
Chronic Pain	• It is generally defined as pain that persists for more than three months. • Chronic pain, due to its prolonged duration, may lead to adverse outcomes such as anxiety, depression, and avoidance behaviors driven by fear of pain (Raja et al., 2020).

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Classification of Pain According to Mechanisms

Table 2. Classification of Pain According to Mechanisms

Neuropathic Pain	• It occurs as a direct consequence of a lesion or disease affecting the somatosensory system (e.g., stroke, diabetes). • The resulting nerve damage leads to responses such as hyperreactivity, hypersensitivity, and ectopic excitation (Raja et al., 2020).
Nociceptive Pain	• It is pain perceived by nociceptors and transmitted to the central nervous system as a result of tissue damage. • Most of the pain commonly experienced in daily life falls within this category. • An example of this type of pain is the sharp sensation felt immediately after striking one's foot, followed by a second, sharp but slower pain (Raja et al., 2020).
Nosiplastic Pain	• The term *nociplastic* is derived from the concept of "nociceptive plasticity," referring to the flexibility of nociception and pain perception. • This type of pain arises from alterations in pain processing despite the absence of any actual or potential tissue damage or threat. • Fibromyalgia is one of the conditions commonly cited as an example of nociplastic pain (Raja et al., 2020).

Kinesiophobia

Kinesiophobia, derived from the combination of the Greek words *"kinesis"* (movement) and *"phobus"* (fear), literally refers to the "fear of movement" (Kvist et al., 2005). This condition describes the avoidance of movement due to fear of pain or reinjury and is frequently observed during physical therapy or rehabilitation processes. By limiting movement, kinesiophobia may negatively affect the recovery period. First introduced by Kori and colleagues in 1990, kinesiophobia was defined as an excessive and debilitating fear of physical movement and activity arising from a feeling of vulnerability to reinjury or painful injury (Knapik et al., 2011; Burwinkle et al., 2005). Kinesiophobia can hinder individuals from engaging in movement due to perceived risks of pain or injury, thereby adversely affecting recovery and leading to functional limitations.

An individual may alter their movement patterns to avoid pain, which in turn negatively influences pain management. The fear of movement can act as a barrier when exercise is recommended and may reduce a patient's adherence to treatment (Larsson et al., 2016).

When any part of the body is exposed to injury, pain typically restricts movement and may lead to a persistent fear of movement even after the healing process has been completed. This condition can affect an individual's pain perception, limit daily activities, and negatively impact quality of life. Kinesiophobia that develops in response to pain may lead individuals to restrict physical activity, thereby prolonging the recovery process (Luque-Suarez et al., 2019, Şahiner & Koca 2021). In the progression of pain from the acute to the chronic stage, kinesiophobia is considered a central factor. Although pain initially emerges as a protective response of the body, fear of movement may develop in cases of prolonged pain, contributing to the chronicity of pain (Larsson et al., 2016).

Kinesiophobia may induce behavioral, physical, and cognitive forms of fear in patients. Behaviorally, individuals may refuse or restrict movement to avoid pain. Physically, muscle tension, postural abnormalities, and limitations in joint range of motion may develop. At the cognitive level, patients may form a persistent belief that movement will exacerbate pain, reinforcing fear and negatively influencing the recovery process. These fears across the three domains can reduce functional capacity and severely impair quality of life (Edwards et al., 2011).

Kinesiophobia is also thought to be associated with the limbic system. The limbic region of the brain is a critical center responsible for regulating and controlling emotions, fears, and behaviors related to survival-driven responses. This system plays a key role in processing the emotional and cognitive reactions associated with pain. Since kinesiophobia involves the coexistence of pain and fear of movement, hyperactivation of limbic structures related to anxiety, fear, and stress may contribute to the development of these fears and avoidance behaviors. Such mechanisms may make it more difficult for individuals to cope with pain and the fear of movement, thereby negatively affecting their recovery processes (Leeuw et al., 2007; Meier et al., 2016,Koca et al 2013).

Kinesiophobia has been found to be associated with lower levels of physical activity in individuals experiencing chronic pain (Larsson et al., 2016). According to the fear-avoidance model, when a painful experience is perceived as a threat, it may lead the individual to develop the belief that physical activity will result in increased pain or reinjury. As this belief persists, it can ultimately lead to long-term disability, inactivity, and depression. Additionally, escalating pain may reinforce avoidance behaviors by contributing to a cycle of increased fear of pain and injury (Vlaeyen et al., 1995). Physical inactivity induces a series of physiological changes in skeletal muscle, creating an imbalance between myofibrillar protein synthesis and degradation, which results in reduced muscle mass and atrophy (Kubat et al., 2023).

In cases of chronic pain, kinesiophobia often negatively affects participation and adherence to rehabilitation programs. Assessing the level of kinesiophobia prior to initiating an exercise program may help address the issue through more appropriate rehabilitation strategies. For instance, establishing realistic functional goals, identifying and modifying safe movements, and gradually increasing exposure to feared physical activities—similar to behavioral therapy approaches—are recommended strategies (Luque-Suarez et al., 2019).

Treatment of Kinesiophobia

Therapeutic exercises and cognitive-behavioral therapy (CBT) play a central role in managing kinesiophobia.

Therapeutic Exercises: By increasing muscle strength and improving mobility, therapeutic exercises contribute to effective pain management. Safely engaging individuals in physical activity may help reduce fear of movement. Exercise can decrease pain levels and promote overall well-being by enhancing muscle strength and range of motion. Cognitive-behavioral therapy focuses on modifying negative thoughts related to pain and movement. Together, these two approaches support individuals in overcoming kinesiophobia and adopting a healthier lifestyle (Güzel et al., 2021).

Cognitive-Behavioral Therapy (CBT): Patients with chronic pain often develop maladaptive, catastrophic beliefs and expectations regarding the persistence and progression of their pain. They may struggle to cope with thoughts related to loss of independence, vulnerability, and rapid deterioration of their condition. Therefore, CBT is applied in individuals with chronic pain to restructure these negative thoughts and beliefs and to foster healthier coping strategies. By targeting the maladaptive cognitions underlying kinesiophobia, CBT enables individuals to reinterpret these thoughts in a more realistic and functional manner. Techniques such as confrontation of fears and gradual exposure are commonly employed (Cheng & Cheng, 2019).

Fear-Avoidance Model

In the past, fear related to pain has been conceptually defined in various ways. Among the most commonly used terms are “pain-related fear,” “fear-avoidance tendency,” “fear of movement,” and “kinesiophobia” (Lundberg et al., 2011). Recent research suggests that kinesiophobia consists of two sub-factors: one is *somatic focus*, which reflects concerns about an underlying serious medical condition, and the other is *activity avoidance*, which stems from the belief that movement may lead to further injury (Vincent et al., 2011; Roelofs et al., 2007; Woby et al., 2005).

Fear-avoidance tendency refers to a condition in which pain is pessimistically interpreted, leading individuals to avoid behaviors that may cause pain and to experience fear or anxiety about the recurrence of pain (Sugano et al., 2020). In an attempt to explain how and why some individuals develop chronic pain syndromes, the *Fear-Avoidance Model* was introduced (Lethem et al., 1983).

Following this conceptualization, several seminal articles have emerged that broaden and summarize cognitive-behavioral models related to fear-avoidance (FA) tendencies (Vlaeyen et al., 1995).

The central concept of this model is fear of pain. *Confrontation* and *avoidance* are considered two extreme responses to this fear, with the former leading to a gradual reduction in fear over time. The latter, however, can result in a phobic state, contributing to the persistence or intensification of pain. Avoidance leads to a reduction in both social and physical activities, which in turn triggers a series of physical and psychological problems that exacerbate disability. Consequently, kinesiophobia has been recognized as a psychological construct within the fear-avoidance model (Vlaeyen et al., 1995; Vlaeyen & Linton, 2000).

Some studies have found that fear-avoidance tendencies contribute to muscle weakness and reduced range of motion. According to the fear-avoidance model, kinesiophobia, together with pain, can lead to reluctance to move and subsequent disability. Furthermore, high levels of fear-avoidance tendencies have been observed to be directly associated with increased levels of disability (Leeuw et al., 2007; Sugano et al., 2005; Cook et al., 2006; Alizadehkhaiyat et al., 2007).

Figure 1. Fear-Avoidance Model

Measurement of Kinesiophobia

Tampa Kinesiophobia Scale:

Tampa Kinesiophobia Scale was developed by Vlaeyen et al. (1995) and Turkish adaptation and validity and reliability analysis were conducted by Yılmaz et al. (2011). The tampa kinesiophobia scale is a 17-question scale to measure the fear of re-injury. The questions in the scale are evaluated in likert type between "1- Strongly Disagree" and "4-Strongly Agree". As a result of the questionnaire, the person receives a score between the lowest 17 and the highest 68 points according to his/her answers. The higher the scores obtained from the scale, the higher the person's fear of movement and injury (Vlaeyen et al., 1995).

Kinesiophia and Sport

In musculoskeletal pain, kinesiophobia in patients has been reported to be associated with increased pain during movement, higher pain intensity, functional limitations, and reduced physical activity (Perrot et al., 2018; Westman et al., 2011). Furthermore, a positive relationship between activity-induced pain and kinesiophobia has also been observed (Martinez-Calderon, 2018; Mintken et al., 2010). In this context, kinesiophobia has been linked to decreased performance in functional skills (Vlaeyen & Linton, 2000) and impairments in activities of daily living (Waddell et al., 1993; Thomas et al., 2010).

The pain-avoidance tendencies induced by kinesiophobia can alter individuals' movement patterns. Such changes may lead to maladaptive motor habits that negatively affect the performance of actions related to the management and control of pain and pain-related disability (Karos et al., 2017). Individuals experiencing kinesiophobia may feel psychological and physical discomfort, such as fatigue, frustration, and pain, due to anxiety about the consequences of their movements. This can result in the development of distinctive and exaggerated behavioral patterns aimed at avoiding past experiences (Özkal et al., 2017; Uçurum & Kalkan, 2018). In individuals with kinesiophobia, the belief that movement may lead to reinjury or increased pain is prevalent (Kori et al., 1990). This belief can heighten vigilance, disrupt sleep, and contribute to anxiety (Vlaeyen et al., 1995). Over time, such responses may result in reduced physical activity, avoidance behaviors, functional limitations, non-use of affected extremities, depression, and a decline in quality of life (Vlaeyen et al., 1995).

The ultimate goal following injury is always to facilitate a return to sports activities. However, only 85% of athletes are able to return to sports after surgery, and among these, merely 65% reach their pre-injury levels of sporting activity (Ardern et al., 2011; Wiger et al., 1999). Of those who return, only 56% are reported to participate in competitive sports (Ardern et al., 2011). The inability to regain pre-injury levels is influenced by multiple factors, with fear of reinjury being one of the most frequently encountered reasons (Webster et al., 2008). In a study across different sports disciplines, Van Melick et al. (2022) found that one-third of athletes did not return to sport due to fear of reinjury. Similarly, Ekizoğlu and Sever (2023) reported that athletes who experienced anterior cruciate ligament injuries exhibited fear of reinjury and were not mentally prepared to resume sports participation.

In the early phase following a sports injury, the most commonly observed psychological issue is depressive mood. Such injuries can elicit a range of negative psychological responses in athletes, including fear, stress, anxiety, irritability, and depressive feelings. These adverse states tend to decrease over time. Research emphasizes that an athlete's psychological state is crucial for a full return to sport. Positive psychological factors facilitate the likelihood and process of returning to sport, whereas fear and avoidance negatively impact recovery and the return-to-sport process. Among the psychological factors associated with post-injury pain, fear is considered one of the most fundamental (Kaçoğlu et al., 2018).

Kinesiophobia can negatively affect treatment, rehabilitation, and return-to-sport outcomes in athletes following injury (Kvist et al., 2005). Incomplete adherence to rehabilitation protocols or failure to fully achieve clinical targets may increase the risk of reinjury in the same region. Consequently, athletes may exhibit avoidance behaviors toward exercise and movement due to fear of reinjury (Heijne et al., 2008).

A study reported that 20–24% of athletes were unable to successfully return to sport following anterior cruciate ligament surgery due to kinesiophobia (Kvist et al., 2005). The incidence of kinesiophobia has been reported to be as high as 52.8% in patients following traumatic injuries (Morgounovski et al., 2016). In cases of chronic pain, the prevalence of kinesiophobia has been estimated to range between 50% and 70% (Luque-Suarez et al., 2019).

In light of the aforementioned evidence, kinesiophobia represents a critical psychosocial factor in the sustainability of athletic performance and the effective management of return-to-sport processes following injury. Increased fear of movement in athletes not only limits physical capacity but also negatively affects training adherence, motivation, and self-confidence. Particularly during the rehabilitation period, high levels of kinesiophobia can prolong recovery and cause delays in returning to sport. Therefore, early assessment and intervention targeting kinesiophobia are essential for preserving performance and ensuring an optimal post-injury return to sport.

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Chapter 4

Exercise and Sport in Children with Autism

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Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition with onset in early development, characterized by persistent difficulties in social communication and social interaction, accompanied by restricted and repetitive patterns of behavior (e.g., excessive adherence to routines, circumscribed interests, and atypical responses related to sensory differences) (American Psychiatric Association, 2013; Lord, Elsabbagh, Baird, & Veenstra-Vanderweele, 2018). The designation "spectrum" underscores substantial inter-individual variability in symptom severity, language development, cognitive profile, comorbidities, and functional level. This heterogeneity necessitates, in exercise and sport participation as in educational and rehabilitation contexts, individualized adaptations that are responsive to each child's needs and that support sustainable participation, rather than a one-size-fits-all approach (Lai, Lombardo, & Baron-Cohen, 2014; Lord et al., 2018).

In children with ASD, physical activity and sport are increasingly viewed not only in terms of "physical health," but also as functional domains that can promote participation in daily life, support behavioral regulation and self-regulation, and expand opportunities for social interaction (Bremer, Crozier, & Lloyd, 2016; Healy, Nacario, Braithwaite, & Hopper, 2018). At the same time, core clinical features of ASD may directly influence engagement in sport. Sensory processing differences (e.g., sensitivity to noise, crowds, lighting, or tactile stimuli), difficulties tolerating changes in routine, and limitations in social communication can render sport settings challenging and may hinder sustained participation (Tomchek & Dunn, 2007; American Psychiatric Association, 2013). Difficulties in motor coordination and motor planning—commonly reported in ASD—may further constrain the acquisition of fundamental movement skills, the progression to sport-specific skills, and the ability to engage in shared activities with peers, thereby indirectly reducing participation (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). Moreover, several studies have noted that children

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with ASD may be at increased risk for obesity and physical inactivity, highlighting the importance of regular physical activity as a protective health behavior (Curtin, Anderson, Must, & Bandini, 2010; Bull et al., 2020).

Within this context, systematic reviews and meta-analyses examining the effects of exercise and sport in ASD indicate that structured physical activity interventions can produce generally favorable outcomes not only in motor competence and components of physical fitness, but also in selected behavioral indicators—particularly stereotyped behaviors—and social participation (Sowa & Meulenbroek, 2012; Bremer et al., 2016; Healy et al., 2018; Ferreira et al., 2019). For example, evidence suggests that structured aquatic activities, including swimming, may support both skill development and markers of social behavior (Pan, 2010). Applied research conducted in Türkiye is similarly noteworthy, as it demonstrates that adapted exercise training can yield improvements in components of physical fitness (Yanardağ, Ergun, & Yılmaz, 2009). Nevertheless, because intervention types, duration/intensity parameters, and outcome measures vary considerably across studies, the interpretation of results is highly dependent on individual differences and the implementation context, including environmental stimulus management, instructional supports, and family involvement (Bremer et al., 2016; Healy et al., 2018).

The aim of this book chapter is to (i) delineate the core characteristics of ASD and its historical and conceptual foundations—taking into account the shift from the framework of Pervasive Developmental Disorders to the contemporary spectrum conceptualization—(ii) describe motor developmental characteristics in children with ASD, and (iii) evaluate the potential contributions of exercise and sport across mental, physical, and social domains through an evidence-based lens (American Psychiatric Association, 2013; Tortamış Özkaya, 2013). The chapter is structured along the following sequence—definition, historical background, etiology, symptoms, motor development, effects of sport/exercise, and conclusion and evaluation—with the goal of providing readers with an integrated, accessible, and practice-relevant framework.

Autism

Autism/Autism Spectrum Disorder (ASD) is a condition defined clinically by behavioral criteria, with diagnosis based on the combined evaluation of (i) persistent impairments in social communication and social interaction and (ii) restricted and repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). In contemporary classification systems, ASD is situated under the umbrella of "neurodevelopmental disorders." In ICD-11, ASD is characterized by marked difficulties in initiating and sustaining reciprocal social interaction and social communication, together with clearly atypical, excessively restricted, and repetitive patterns of behavior, interests, and activities (World Health Organization, 2019; Kamp-Becker et al., 2024).

The DSM-5 framework additionally emphasizes the use of severity specifiers in terms of “levels of support required” (Levels 1–3), reflecting the extent to which symptoms interfere with daily functioning. This emphasis provides a practical language for planning the type and intensity of assistance a child may need in educational and sport settings (Centers for Disease Control and Prevention, 2025; American Psychiatric Association, 2013).

The historical evolution of the autism concept illustrates that both terminology and classification have shifted substantially over time. The term *autism* was first introduced in 1911 by Eugen Bleuler to describe withdrawal from the external world and inward-focused thought patterns observed in cases then conceptualized within schizophrenia (Jutla, Donoghue, & FitzGerald, 2021). The modern clinical description of childhood autism became more clearly delineated in 1943, when Leo Kanner described 11 children and highlighted distinctive features in social relatedness, communication patterns, and repetitive behaviors, framing autism as a specific clinical presentation of childhood (Kanner, 1943). One year later, Hans Asperger (1944) detailed a different clinical profile marked by social interaction difficulties and circumscribed interests, often accompanied by relatively strong language and cognitive abilities. Asperger’s account formed the historical basis for the group later referred to as “Asperger syndrome” in the literature (Asperger, 1944; Wing, 1981).

With respect to diagnostic nosology, during the DSM-IV era autism was addressed under the umbrella of Pervasive Developmental Disorders (PDD) as distinct categories (Autistic Disorder, Asperger’s Disorder, Rett’s Disorder, Childhood Disintegrative Disorder, and PDD–Not Otherwise Specified) (McPartland, Reichow, & Volkmar, 2012). In DSM-5, these subcategories were consolidated under the single diagnosis of Autism Spectrum Disorder, largely because distinctions among subtypes were not consistently reliable in clinical practice and because symptom presentations often reflect a continuum rather than discrete entities (American Psychiatric Association, 2013). This shift has reinforced a contemporary view of ASD as a single spectrum in which heterogeneity is described through specifiers and associated features (e.g., language level, cognitive profile, and comorbid conditions) rather than separate diagnostic labels (Lord et al., 2018).

Etiology of Autism

The etiology of ASD is multifactorial and cannot be reduced to a single cause. Current models emphasize that ASD risk is largely grounded in genetic liability, which may interact with prenatal and perinatal environmental factors and broader biological processes to yield heterogeneous clinical presentations (Lord, Elsabbagh, Baird, & Veenstra-Vanderweele, 2018). Accordingly, the "etiology" domain should be approached not as a search for a singular disease agent, but as an integrative framework in which multiple risk factors and mechanisms are considered jointly.

Genetic and neurobiological foundations

Evidence from family and twin studies indicates high heritability for ASD; however, the underlying genetic architecture is better understood as polygenic rather than a "single gene–single phenotype" pattern. That is, numerous genetic variants are thought to contribute to risk, with effects distributed across multiple pathways (Lord et al., 2018). Genetic influences may increase ASD susceptibility through mechanisms that shape synaptic development, neuronal connectivity, network organization, and the timing of neurodevelopmental processes (Lord et al., 2018). From this perspective, etiological inquiry is less about identifying a discrete "defect" and more about explaining how variability in neurodevelopmental pathways may be associated with elevated risk.

Environmental and prenatal/perinatal risk factors

Environmental factors are typically considered within sensitive developmental windows, including pregnancy, the perinatal period, and early life. Turkish-language review articles have noted that factors such as advanced parental age, certain medical conditions during pregnancy, prenatal exposures, and perinatal processes may be associated with increased risk, while also emphasizing that establishing definitive causality remains challenging in many instances (Özbaran, 2014). Similarly, another review argues that ASD etiology should be conceptualized as an interaction of genetic, neurobiological, and environmental influences, and that explanations reducing ASD to environmental factors alone are scientifically insufficient (Gök Dağıdır et al., 2022). A shared emphasis across such reviews is that much of the evidence regarding environmental influences reflects associations with risk rather than conclusive causal pathways; therefore, clinical and practical interpretations should prefer cautious language (e.g., "may be associated with risk") rather than definitive "cause" statements (Özbaran, 2014; Gök Dağıdır et al., 2022).

Symptoms of Autism

Within the diagnostic framework, ASD symptoms cluster into two broad domains: (i) deficits in social communication and social interaction, and (ii) restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). Symptom severity and presentation may vary as a function of age, language development, cognitive profile, and co-occurring difficulties or strengths. Therefore, clinical evaluation is grounded not merely in a binary "present/absent" approach, but in the extent to which symptoms interfere with everyday functioning (American Psychiatric Association, 2013).

Symptoms in social communication and social interaction

Social difficulties in ASD may be observed as limited reciprocal social–emotional exchange, challenges in using verbal and nonverbal communicative behaviors (e.g., eye contact, facial expressions, gestures), and impairments in developing, maintaining, and understanding relationships (American Psychiatric Association, 2013). In early childhood, differences may be noted in initiating or sustaining joint attention, responding to one's name, social smiling, and reciprocal play; during the school years, challenges may become more salient in peer relationships, rule-governed play, and social flexibility (American Psychiatric Association, 2013).

Restricted and repetitive behaviors and sensory differences

Repetitive motor movements, atypical use of objects, inflexible adherence to routines, highly restricted and fixated interests, and hyper- or hyporeactivity to sensory input are considered central features of ASD (American Psychiatric Association, 2013). Turkish overview literature likewise frequently highlights rigid adherence to routines, repetitive motor patterns, and atypical sensory responses as distinguishing characteristics of ASD (Savucu, 2020). A critical implication for exercise and sport contexts is that environmental stimuli—such as noise, crowds, lighting, and tactile input—may exacerbate symptom expression for some children, whereas structured and predictable activities may support regulation in the same individuals. Accordingly, symptoms should be approached not only as a "diagnostic list," but also as context-sensitive variables that shape participation in real-world practice settings (American Psychiatric Association, 2013).

Motor Developmental Characteristics in Children With Autism

Although motor development was long treated as a secondary domain within the ASD literature, contemporary evidence indicates that motor skill differences are common in ASD and can directly influence participation in daily life. Difficulties have been reported with balance, coordination, motor planning (praxis), bilateral coordination, fine motor control, and fundamental movement skills (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). Such motor profiles may also exert downstream effects on social participation by constraining a child's play repertoire and limiting opportunities for peer interaction (Fournier et al., 2010).

A review published in Türkiye emphasizes the presence of motor skill differences in children with ASD and highlights the importance of increasing the visibility of the motor domain through appropriate assessment tools, both in educational settings and in exercise applications (Su and Taşkıran, 2022). From an implementation standpoint, identifying motor differences constitutes a critical step prior to "sport selection," as it clarifies which task demands are challenging for the child and what forms of support are required (Su and Taşkıran 2022).

Turkish experimental evidence further suggests that adapted exercise interventions may be effective in improving motor and physical fitness outcomes. For instance, a study examining the effects of adapted exercise training on physical fitness in children with autism—despite its small sample size—reported observable changes in domains such as cardiorespiratory endurance, strength, agility, and flexibility (Yanardağ, Ergun, & Yılmaz, 2009). Such findings reinforce the notion that motor development is not only an observational domain but also a measurable and modifiable target for intervention (Yanardağ et al., 2009).

In practical terms, if a child with ASD experiences difficulty with tasks such as catching/throwing a ball, changing direction, keeping rhythm, or maintaining balance, these challenges should not be interpreted as mere "unwillingness." Rather, they should be understood as indicators of motor coordination and planning demands. This perspective can facilitate more frequent experiences of success and may help prevent or manage certain problem behaviors—such as avoidance, frustration, or leaving the session—through proactive task adaptation and support (Su and Taşkıran, 2022).

Autism as a Spectrum Disorder

Pervasive Developmental Disorders

The concept of **Pervasive Developmental Disorders (PDD)**, as used in the DSM-IV/DSM-IV-TR era, served as an umbrella term for clinical presentations characterized by pervasive (i.e., affecting multiple developmental domains) and persistent impairments in social interaction, communication, and behavioral patterns. Within this framework, in addition to Autistic Disorder, the diagnoses of Asperger's Disorder, Childhood Disintegrative Disorder, Rett's Disorder, and PDD–Not Otherwise Specified (PDD-NOS) were specified as distinct categories (Özbaran, 2009).

With the publication of DSM-5, the DSM-IV-TR diagnoses of Autistic Disorder, Asperger's Syndrome, PDD-NOS, and Childhood Disintegrative Disorder were consolidated under a single spectrum-based diagnosis, **Autism Spectrum Disorder (ASD)**. The primary rationale for this change was the limited reliability of distinguishing subtypes in routine clinical practice and the observation that symptom severity and presentation tend to vary along a continuum rather than forming discrete categories. **Rett syndrome**, given its more clearly delineated genetic basis, was positioned outside the ASD umbrella in DSM-5 (Tortamış Özkaya, 2013).

Asperger Syndrome: Historically, Asperger syndrome was described as a clinical profile characterized by marked difficulties in social interaction and restricted, intense interests, often in the absence of significant language delay or intellectual disability (Asperger, 1944; Wing, 1981). Asperger's original descriptions emphasized reduced social reciprocity, difficulties with empathy, one-sided or monotonic communication, "special interests," and a degree of rigidity that could affect everyday functioning (Asperger, 1944; Wing, 1981). In clinical practice, one of the frequently noted features associated with the Asperger profile has been **motor clumsiness and coordination difficulties**. In the context of sport and physical activity, such difficulties may influence participation through challenges related to balance, rhythm, ball skills, and peer interaction within team settings (Özdemir & İşeri, 2005). Moreover, because Asperger syndrome was sometimes perceived as indicating "high functioning," support needs could be underestimated in practice. This makes structured support particularly important in sport environments with respect to understanding social rules, tolerating flexibility, cooperating with peers, and managing sensory demands (Özdemir & İşeri, 2005).

With DSM-5, the diagnostic label *Asperger syndrome* was removed, and this clinical presentation began to be conceptualized within ASD—often corresponding to profiles with comparatively lower support needs—consistent with a dimensional, spectrum-based approach. This shift has been linked to ongoing debates regarding the clinical reliability of subtype distinctions and to the explanatory utility of spectrum conceptualizations (Tortamış Özkaya, 2013).

Rett Syndrome: Rett syndrome is a neurodevelopmental disorder observed predominantly in girls, characterized by a period of apparently typical early development followed by regression, including loss of purposeful hand use, stereotypic hand movements, decline in communication, and frequently co-occurring neurological signs (Zengin Akkuş & Utine, 2016). The clinical course is often discussed in terms of a plateau phase beginning approximately between 6 and 18 months, followed by more pronounced regression in subsequent stages (Zengin Akkuş & Utine, 2016). A major milestone in the international recognition of Rett syndrome was the case series published by Hagberg and colleagues in 1983 (Hagberg, Aicardi, Dias, & Ramos, 1983). Subsequent consensus efforts and revised diagnostic criteria further refined the clinical boundaries and diagnostic specification of Rett syndrome (Neul et al., 2010).

Although Rett syndrome was included under the PDD umbrella in earlier DSM systems, the clarification of its genetic underpinnings and its distinctive clinical course relative to ASD led DSM-5 to classify it outside the ASD umbrella (Tortamış Özkaya, 2013). This distinction is clinically valuable in underscoring that "autistic-like features" may occur in certain conditions without implying equivalence to an ASD diagnosis within contemporary diagnostic frameworks (Tortamış Özkaya, 2013; Neul et al., 2010).

Childhood Disintegrative Disorder

Childhood Disintegrative Disorder (CDD; Heller syndrome) is a rare clinical condition in which at least two years of typical or near-typical early development are followed—between approximately 2 and 10 years of age—by marked regression across domains such as communication, social interaction, play, motor skills, and toileting (Yazıcı & Perçinel, 2014). Given its rarity, diagnostic awareness may be limited in clinical settings; therefore, careful evaluation of the pattern and timing of regression is essential for differential diagnosis and follow-up (Yazıcı & Perçinel, 2014). Historically, Heller's 1908 description of cases under the term *dementia infantilis* provided the conceptual foundations for later formulations of CDD (Mouridsen, 2003). The inclusion of CDD as a distinct category in DSM-IV aimed to highlight not only its overlap with autism-related phenotypes, but also its defining features of later onset and dramatic regression (Volkmar, 1992). With DSM-5, CDD ceased to exist as a separate diagnostic label and was subsumed under ASD. Turkish discussions of the transition to DSM-5 have also considered the clinical and educational implications of integrating CDD under the ASD framework (Tortamış Özkaya, 2013).

PDD–Not Otherwise Specified (PDD-NOS)

In DSM-IV-TR, PDD-NOS was used for a heterogeneous group of individuals who exhibited significant impairments in social interaction along with autistic features in communication and/or behavior, but who did not meet full criteria for another specific PDD diagnosis. The frequent clinical use of this category was largely attributable to the fact that developmental symptoms may not be fully articulated in early childhood and that clinical presentations often do not conform to sharply bounded subtype distinctions (Tortamış Özkaya, 2013). The heterogeneity of PDD-NOS also raised questions concerning diagnostic stability and longitudinal outcomes. Naturalistic follow-up findings from Türkiye indicate that some children diagnosed with PDD-NOS in the preschool period may later experience diagnostic change, whereas others remain within the spectrum over time (Köse, Ocakoğlu, Ocakoğlu, & Özbaran, 2017). Such findings align with the clinical rationale for DSM-5's single-spectrum approach: early symptoms may initially be subthreshold, yet patterns and severity can become clearer as development progresses (Köse et al., 2017).

Contemporary literature further suggests that, following DSM-5's consolidation of PDD-NOS under ASD, conceptual and legal/institutional adaptation processes may become increasingly salient in the clinical monitoring and service access of individuals who previously received a PDD-NOS diagnosis (Carbone et al., 2023).

The Effects of Sport on Individuals With Autism

Sport and Autism

Sport, broadly defined, encompasses planned and structured physical activities; more narrowly, it refers to competitive or recreational activities governed by specific rules, goals, and performance components. In the context of ASD, sport should be conceptualized not merely as a means of improving "physical fitness," but also as a developmental domain capable of fostering participation, self-regulation, behavioral management, and opportunities for social interaction (Bremer, Crozier, & Lloyd, 2016; Healy, Nacario, Braithwaite, & Hopper, 2018).

Participation in sport among children with ASD varies substantially due to the heterogeneity of the spectrum. Social-communication difficulties, a strong preference for routine, sensory hyper- or hyposensitivity, and motor coordination challenges may render participation particularly sensitive to features of the sport environment such as predictability, stimulus load, and task demands (American Psychiatric Association, 2013; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Tomchek & Dunn, 2007). For this reason, the impact of sport in ASD is often related less to the specific sport itself and more to how the activity is structured and to the environmental adaptations that make participation feasible and sustainable for the child (Bremer et al., 2016).

Systematic reviews and meta-analyses evaluating physical activity and sport interventions in ASD generally report beneficial—but heterogeneous—effects.

Effect magnitudes appear to vary as a function of intervention duration and intensity, the degree of individualization, the outcome domain assessed (motor, behavioral, social), and sample characteristics (Sowa & Meulenbroek, 2012; Healy et al., 2018).

General Information on the Benefits of Sport for Individuals

The benefits of physical activity and sport are supported by a broad evidence base not only for "healthy populations," but also for groups with chronic conditions or special needs. The World Health Organization emphasizes that regular physical activity has robust effects on cardiometabolic health, musculoskeletal health, functioning, and quality of life, and that reducing sedentary behavior should be treated as an independent health target (Bull et al., 2020).

From a physical health perspective, sport enhances cardiorespiratory fitness, supports muscular strength and bone health, reduces the risk of obesity and certain chronic diseases, and strengthens functional capacity and independence in activities of daily living (Warburton, Nicol, & Bredin, 2006; Pedersen & Saltin, 2015). At the population level, a substantial body of research has highlighted that physical inactivity constitutes a major contributor to disease burden and that regular physical activity has significant preventive public health value (Lee et al., 2012).

With respect to mental health and cognitive processes, physical activity is associated with improvements in outcomes related to depressive symptoms, stress, and anxiety in children and adolescents. Evidence syntheses suggest that physical activity may function as a protective factor for psychological well-being and that regular movement—particularly during childhood and adolescence—can have favorable implications for self-regulation and self-perceptions (Biddle & Asare, 2011; Lubans et al., 2016).

From the standpoint of social development, sport constitutes a powerful naturalistic setting that can elicit and reinforce social skills through rule-governed interaction, role taking, cooperation, problem solving, and initiating and maintaining communication. Accordingly, sport in child development is often framed not only as "physical education," but also as a context for "social learning" (Bailey, 2006).

Information on the Cognitive, Physical, and Social Developmental Effects of Sport in Individuals With Autism

In ASD, the effects of sport can be discussed across three primary domains: (i) cognitive/psychological processes, (ii) physical development and motor competence, and (iii) social participation and social skills. Although the evidence base generally points to beneficial outcomes in these areas, findings also indicate that effects do not emerge in an identical manner for every individual and that implementation context plays a decisive role (Sowa & Meulenbroek, 2012; Bremer et al., 2016; Healy et al., 2018).

Cognitive and psychological development (attention, self-regulation, behavioral patterns)

One of the most frequently reported effects of physical activity in ASD is a tendency toward reductions in certain indicators of problem behavior, particularly stereotyped behaviors. Evidence from systematic reviews and meta-analyses suggests that exercise can have a statistically significant decreasing effect on stereotypic behaviors (Ferreira et al., 2019). Proposed mechanisms include regulation of arousal levels, the development of alternative behavioral repertoires, and support for on-task behavior within structured activity settings (Lang et al., 2010; Bremer et al., 2016).

Findings related to cognitive outcomes such as attention and executive functioning are more heterogeneous. Nevertheless, a meta-analysis examining physical activity interventions indicates that physical activity can generally yield favorable effects in children and adolescents with ASD, with some studies reporting gains in domains such as attention and task engagement (Healy et al., 2018). A critical distinction is that when sport is structured not merely as an opportunity to "release energy," but as a learning environment involving organized tasks and rule-governed interactions, it may contribute more robustly to self-regulatory processes (Bremer et al., 2016).

Physical development and motor competence (coordination, balance, fitness)

Meta-analytic evidence indicating that motor coordination difficulties are common in children with ASD supports the view that sport can serve as a strategic intervention domain for motor development (Fournier et al., 2010). Improvements in motor competence may strengthen motivation for sport participation, reduce avoidance behaviors by decreasing repeated experiences of failure, and facilitate the development of a richer repertoire of play and sport skills (Fournier et al., 2010).

One meta-analysis reported that exercise in ASD can produce generally favorable effects on motor performance and social outcomes, noting that individual-based interventions may yield more pronounced improvements for certain outcomes (Sowa & Meulenbroek, 2012). Experimental research conducted in Türkiye likewise reported improvements in components of physical fitness (e.g., endurance, strength, flexibility) following adapted exercise training (Yanardağ, Ergun, & Yılmaz, 2009). Collectively, these findings indicate that sport in ASD should not be reduced to "social" goals alone; motor and health parameters should also be treated as measurable and meaningful targets (Yanardağ et al., 2009).

Social life and participation (communication, peer interaction, play skills)

Social outcomes represent one of the most valuable—yet also the most context-sensitive—domains of sport effects in ASD. Sport environments naturally elicit social processes such as turn-taking, rule-following, shared goal formation, role negotiation, and peer interaction. Accordingly, structured physical activity interventions have been reported to produce beneficial effects on social skills and social participation (Sowa & Meulenbroek, 2012; Bremer et al., 2016).

In particular, some studies suggest that structured aquatic activities, including swimming programs, may support both motor skills and selected indicators of social behavior (Pan, 2010). However, a key determinant is not to assume that an activity will spontaneously generate social interaction, but rather to design tasks in ways that actively promote social engagement (e.g., paired tasks, peer modeling, shared materials, visual supports, and clearly signaled transitions), while providing supports aligned with the child's social-communication profile (Bremer et al., 2016).

Overall, the literature suggests that sport and structured physical activity in individuals with ASD may be associated with beneficial outcomes in motor competence/physical fitness, selected problem behavior indicators (particularly stereotypies), and social participation (Sowa & Meulenbroek, 2012; Bremer, Crozier, & Lloyd, 2016; Healy, Nacario, Braithwaite, & Hopper, 2018; Ferreira et al., 2019). At the same time, generalizability is partly constrained by limitations that are common in this literature, including small sample sizes, heterogeneity in intervention types (e.g., swimming, aerobic training, strength training, multi-component programs), variability in duration and intensity parameters, differences in outcome measures, and relatively short follow-up periods (Bremer et al., 2016; Healy et al., 2018). Therefore, rather than expecting uniform outcomes across all children, a more realistic framework is to interpret sport effects in ASD through an individualized lens that prioritizes sustainable participation by accounting for the child's sensory profile, motor skill level, social-communication capacity, and environmental conditions (American Psychiatric Association, 2013; Tomchek & Dunn, 2007).

Conclusion and Evaluation

Autism Spectrum Disorder is a neurodevelopmental condition that—due to its developmental characteristics and pronounced individual differences—requires a multidimensional appraisal with respect to education, social life, and health-related behaviors (American Psychiatric Association, 2013). The sources reviewed in this chapter collectively indicate that sport and physical activity for individuals with ASD cannot be reduced to a single objective; rather, they may serve a supportive role across a broad continuum of outcomes, ranging from motor development to behavioral regulation, and from social participation to psychological well-being (Sowa & Meulenbroek, 2012; Bremer et al., 2016; Healy et al., 2018).

From a physical and motor perspective, the high prevalence of motor coordination difficulties in children with ASD—and the participation-limiting effects of these difficulties—renders sport a strategically important domain for targeting motor competence (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). Positive outcomes reported for exercise-based interventions on motor-related indicators further suggest that sport in ASD should not be framed solely as a "social skills tool"; components of physical fitness can also be treated as measurable and meaningful targets within intervention planning (Sowa & Meulenbroek, 2012; Yanardağ, Ergun, & Yılmaz, 2009).

With regard to behavioral and self-regulatory domains, meta-analytic evidence indicating that exercise can reduce stereotyped behaviors is particularly noteworthy (Ferreira et al., 2019). At the same time, the available literature suggests that behavioral gains are often less a function of exercise "by itself" and more closely related to how sport environments are structured—specifically, the management of sensory load and the provision of supports that sustain engagement and participation (Bremer et al., 2016; Tomchek & Dunn, 2007).

In the domain of social life and participation, sport is a valuable setting because it offers rule-governed interaction, shared goal formation, and opportunities for peer engagement in a naturalistic context. However, social gains appear highly sensitive to the deliberate social design of the activity (e.g., paired tasks, peer modeling, explicit rules, and clearly signaled transitions) and to the provision of support aligned with the child's communication capacity (Bremer et al., 2016; Pan, 2010). Accordingly, sport in ASD should be conceptualized not merely as "physical activity," but also as a practice domain that teaches participation and intentionally organizes the social context of engagement.

In synthesis, an overarching conclusion emerges: in many cases, what makes sport effective for individuals with ASD is not primarily the type of sport, but the conditions that make sustained participation feasible. In practice, the following considerations are particularly critical: (i) systematic management of sensory stimuli, (ii) avoiding mislabeling motor difficulties as “lack of motivation,” (iii) teaching tasks through small, structured steps, and (iv) maintaining continuity through collaboration among family, school, and specialist supports (American Psychiatric Association, 2013; Tomchek & Dunn, 2007).

From both research and applied perspectives, there remains a need for studies with larger samples, clearly reported intervention “dose” parameters (duration and frequency), longer-term follow-up, and designs that assess motor and social/behavioral outcomes concurrently (Healy et al., 2018; Bremer et al., 2016). In applied settings, if sport is to become a sustainable routine that supports lifelong health behaviors for individuals with ASD, efforts should prioritize the development of accessible environments and the expansion of trained practitioner capacity (Bull et al., 2020).

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Chapter 5

Regular Physical Activity in Individuals with Hearing Impairment: Happiness, Stress, and Life Satisfaction

Neslihan BAL[1]

Introduction

Hearing impairment may be congenital or acquired, affecting auditory perception and communication to varying degrees and yielding multidimensional consequences for education, employment, social participation, and health outcomes. The World Health Organization (WHO) reports that a substantial proportion of the global population lives with hearing loss, that "disabling" levels of hearing loss affect hundreds of millions of people, and that this burden is projected to increase in the coming years (World Health Organization, 2025).

The lived experience of individuals with hearing impairment cannot be reduced to a sensory difference alone. Barriers within everyday channels of social interaction—such as communication difficulties, fear of being misunderstood, and challenges in accessing services—together with environmental constraints that limit participation and experiences of discrimination, can meaningfully shape psychosocial well-being. Within this framework, elevated stress, intensified social isolation, and lower levels of life satisfaction and happiness emerge as frequently discussed outcomes in the hearing-impairment literature. Consistent with this view, the WHO's *World Report on Hearing* emphasizes that hearing loss is not solely a medical issue but also a public health concern that requires community-based responses targeting functioning and well-being (Chadha & Kamenov, 2021).

Beyond its established benefits for physical health in the general population, physical activity constitutes an evidence-based behavioral domain associated with affect regulation, psychological well-being, and quality of life. The WHO guidelines on physical activity and sedentary behavior indicate that recommended levels of physical activity confer health benefits across age groups and are applicable to individuals with disabilities as well (Bull et al., 2020; World Health Organization, 2024).

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The constructs of happiness, stress, and life satisfaction provide three complementary lenses for understanding the psychosocial effects of physical activity. The prevailing approach to assessing life satisfaction focuses on a cognitive judgment through which individuals evaluate their lives as a whole (Diener et al., 1985). In contrast, the classical line of research on stress has operationalized the subjective dimension of stress via the concept of perceived stress (Cohen, Kamarck, & Mermelstein, 1983).

Synthesis evidence examining the relationship between physical activity and happiness/well-being generally points to a positive association across diverse samples and study designs (Zhang & Chen, 2018). However, these patterns cannot be directly extrapolated to individuals with hearing impairment without accounting for context-specific determinants, including accessible communication, peer and community support, opportunities for social participation, and the sustainability of long-term engagement in activity.

Recent studies conducted with hearing-impaired samples further suggest that meaningful links can be established between physical activity/activity participation and psychosocial well-being. For example, in a Turkish sample of children with hearing impairment, activity performance was positively associated with psychological well-being, and participation was emphasized as a construct that should be considered alongside psychosocial health and executive functions (Göktaş et al., 2025). In another study using a long-term recreational intervention design, psychological well-being and life satisfaction were reported to increase significantly among individuals with hearing impairment (Bingölbalı, Kızılkaya, & Evcimi, 2025). International work has also discussed the possibility that regular physical activity may play a moderating role, strengthening associations between happiness/well-being and psychosocial resources such as self-efficacy and resilience among deaf and hard-of-hearing youth (Zhan, 2025).

Accordingly, the aim of this book chapter is to present an integrated account of the relationship between regular physical activity and happiness, stress, and life satisfaction in individuals with hearing impairment, grounded in conceptual foundations, current evidence, and plausible mechanisms. The chapter will proceed through (i) hearing impairment and its psychosocial context, (ii) the basic framework of physical activity and relevant health recommendations, (iii) the conceptualization of happiness, stress, and life satisfaction, (iv) empirical findings in hearing-impaired samples, and (v) an integrative evaluation followed by conclusions. In doing so, the chapter seeks to provide a systematic line of reasoning informed by both national and international literature.

Hearing Impairment

Although the terms hearing loss, hearing impairment/disability, and deafness are sometimes used interchangeably in the literature, they carry distinct emphases, particularly within psychosocial discourse. The World Health Organization (WHO) conceptualizes hearing loss primarily in relation to auditory thresholds and functional consequences and defines "disabling" hearing loss as hearing loss greater than 35 dB in the better-hearing ear (World Health Organization, 2025b).

In contrast, psychosocial and cultural perspectives argue that Deaf identity (capitalized) may, in certain contexts, be understood not merely as a medical designation but also in relation to sign-language–based community belonging, social networks, and cultural identity. From this standpoint, the primary mode of communication (sign language vs. spoken language), educational settings, and broader societal attitudes are treated as key determinants shaping identity development and well-being (Jones, 2002; Sekoto, Ramma, & Sebothoma, 2023).

Classification of Hearing Loss

Classifying hearing loss is critical for accurately characterizing study samples and ensuring that findings are comparable across investigations. Common classification dimensions include the following:

Classification by degree (dB level): In practice, stepwise categories such as normal, mild, moderate, severe, and profound are commonly used. University course materials and clinical training notes typically indicate that thresholds of 0–25 dB correspond to normal hearing, whereas thresholds of ≥26 dB reflect hearing loss of increasing severity, with the nature of communication difficulty varying across levels. The World Health Organization (WHO) similarly notes that hearing loss can be classified as mild, moderate, moderately severe, severe, and profound (World Health Organization, 2025a).

Classification by type (etiology/site of lesion): Hearing loss is frequently categorized according to the primary anatomical/functional locus:

- **Conductive hearing loss:** problems in sound transmission arising from the outer and/or middle ear;
- **Sensorineural hearing loss:** involvement of the inner ear and/or auditory nerve pathways;
- **Mixed hearing loss:** combined conductive and sensorineural components. The WHO emphasizes that hearing loss is not a uniform condition and may arise from diverse causes and at different anatomical or functional levels (World Health Organization, 2025a).

Classification by laterality: Hearing loss may be unilateral (one ear) or bilateral (both ears). This distinction can influence the magnitude and nature of psychosocial effects, particularly with respect to social participation and communication strategies (Sekoto et al., 2023).

Classification by onset: The distinction between congenital/early-onset and acquired hearing loss is a key determinant of language/communication development and educational experiences. The literature on identity development and psychosocial well-being also suggests that onset timing may be meaningfully associated with communication modality and the social environment (Sekoto et al., 2023).

The Relationship Between Regular Physical Activity and Happiness in Individuals With Hearing Impairment

Happiness is widely conceptualized as a core component of subjective well-being, encompassing both individuals' cognitive evaluations of their lives (i.e., life satisfaction) and their affective experiences (i.e., positive and negative affect) (Diener, 1984). Among individuals with hearing impairment, happiness may be shaped by a range of contextual factors, including communication barriers, restricted opportunities for social participation, experiences of exclusion in peer relationships, and limitations in environmental accessibility. Accordingly, regular physical activity is often regarded as a critical behavioral domain associated with happiness, not only because of its physiological benefits but also due to its potential to broaden social participation and strengthen psychological resources.

The contribution of regular physical activity to happiness can be explained through multiple mechanisms. First, physical activity may facilitate affect regulation at both acute and chronic levels, thereby increasing positive affect and enhancing psychological well-being through improvements in self-perceptions and feelings of competence (Biddle & Asare, 2011). Second, participation in organized sport in particular (e.g., team-based or structured group activities) may render psychosocial gains more salient by fostering social connection, a sense of belonging, and access to social support networks (Eime, Young, Harvey, Charity, & Payne, 2013). From this perspective, happiness should be understood not solely as a function of being "physically active" per se, but also as an outcome closely linked to the social context in which activity participation occurs.

Although studies providing direct evidence in hearing-impaired samples remain limited, available findings suggest that physical activity may be meaningfully associated with happiness. For instance, a master's thesis conducted with individuals with hearing impairment reported a statistically significant increase in happiness scores following a regular physical activity intervention (Göktepe, 2018), implying that physical activity may support the hedonic dimension of well-being (i.e., happiness/positive affect). Furthermore, research with adolescents who have hearing loss indicates that sport participation is associated with a lower likelihood of adverse psychosocial outcomes, whereas the frequency of physical activity alone (e.g., number of active days) may not demonstrate an equally robust association (DeLuca & Rupp, 2022). This distinction underscores that, with respect to happiness, the social and relational structure of participation—namely, engagement within contexts that generate interaction and belonging—may be as critical as regularity itself.

More recent work with deaf and hard-of-hearing youth likewise reports positive associations between regular physical activity and happiness, resilience, and overall well-being, and suggests that physical activity may function as a moderator within broader psychosocial pathways (Zhan, 2025). Collectively, these findings support the view that physical activity should not be framed merely as "physical exertion," but rather as a multidimensional behavior that can contribute to happiness by strengthening psychosocial resources such as self-efficacy and psychological resilience.

The Relationship Between Regular Physical Activity and Stress in Individuals With Hearing Impairment

Stress is a psychophysiological process that emerges when individuals appraise environmental demands as exceeding their resources or as threatening; when chronic, it can substantially undermine mental health and quality of life. The association between physical activity and stress is commonly conceptualized as bidirectional: (i) physical activity may buffer the adverse effects of stress, and (ii) higher stress levels may, in turn, reduce participation in physical activity (Gerber & Pühse, 2009; Stults-Kolehmainen & Sinha, 2014). In individuals with hearing impairment, daily challenges stemming from communication demands and barriers in social interaction may increase the overall stress burden, thereby heightening the relevance of physical activity as a potential regulator of stress-related processes.

Evidence supporting the stress-buffering role of exercise is extensive in the general population. In their comprehensive review, Gerber and Pühse (2009) emphasize that higher levels of exercise/fitness may reduce stress-related health complaints and may exert a protective effect within the broader stress–illness relationship. Nonetheless, the magnitude of this effect appears contingent on factors such as the type and intensity of exercise, the continuity of participation, and the individual's broader psychosocial context (Gerber & Pühse, 2009).

Although the evidence base is more limited for hearing-impaired samples, studies focusing on sport participation are instructive. In a sample of deaf adolescents and young adults, meaningful associations were reported between sport participation and perceived stress, with sport engagement discussed as a potential resource for coping with stress (Aslan, 2019). By contrast, a thesis examining the effects of regular physical activity among individuals with hearing impairment suggested that changes in stress—particularly perceived stress—may not be uniformly strong or consistent across assessments, and that improvements may be confined to specific sub-dimensions (Göktepe, 2018). This heterogeneity underscores both the multidimensional nature of stress and the likelihood that physical activity alone may not exert equivalent effects across all forms of stress.

At this point, the social context of participation becomes pivotal. Findings indicating that sport participation among adolescents with hearing loss is associated with a lower likelihood of adverse psychosocial outcomes (DeLuca & Rupp, 2022) suggest that sport may also serve an indirect buffering function for stress through mechanisms such as enhanced social support, peer acceptance, team belonging, and the stabilizing effects of structured routines. Overall, the literature in hearing-impaired populations supports the potential benefits of regular physical activity for stress-related outcomes, while also indicating that effects may be more pronounced when activity occurs within organized sport settings and when participation is accompanied by robust social-support resources (Gerber & Pühse, 2009; DeLuca & Rupp, 2022).

The Relationship Between Regular Physical Activity and Life Satisfaction in Individuals With Hearing Impairment

Life satisfaction reflects a global evaluation of one's life according to self-defined criteria and represents the cognitive component of subjective well-being (Diener, Emmons, Larsen, & Griffin, 1985). Among individuals with hearing impairment, life satisfaction is shaped by multiple determinants, including perceived health, opportunities for social participation, communication accessibility, educational and employment prospects, and social support. Within this multivariate framework, physical activity may contribute to life satisfaction through both a "health and functioning" pathway and a "participation and belonging" pathway.

The broader disability literature generally indicates that being physically active is associated with quality of life and satisfaction. For example, a study comparing physically active versus inactive individuals with disabilities reported that active groups demonstrated more favorable satisfaction profiles across multiple life domains (Nemček, 2016). Such findings support the view that, irrespective of disability type, physical activity may function as a lifestyle determinant that promotes life satisfaction.

Evidence specific to individuals with hearing impairment is more limited but points in a positive direction. In a thesis examining the effects of regular physical activity in individuals with hearing impairment, statistically significant increases in life satisfaction scores were reported following the intervention (Göktepe, 2018). This pattern suggests that physical activity may enhance life satisfaction by improving perceived health, strengthening functional capacity in everyday life, and building psychological resources. Additionally, a study conducted with athletes with disabilities (including visual, physical, and hearing impairments) found a positive association between leisure satisfaction and psychological well-being, with deaf athletes reporting higher scores on certain sub-dimensions (Gürkan, Koçak, & Başar, 2021). Although life satisfaction was not directly measured in that study, the favorable pattern observed in closely related constructs provides indirect support for a congruent association between physical activity/sport participation and life satisfaction.

From this perspective, the physical-activity components most likely to enhance life satisfaction should not be reduced to "regular movement" alone. Rather, life satisfaction may be optimized when participation is supported by enabling environmental conditions—such as accessible facilities, communication supports (e.g., staff proficient in sign language), a psychologically safe social climate, and inclusive team cultures (Diener, 1984; Gürkan et al., 2021). Accordingly, life satisfaction among individuals with hearing impairment may be influenced not only by the quantity of activity but also by the extent to which participation is accompanied by meaningful social inclusion and acceptance.

Conclusion and Evaluation

The available evidence indicates that, among individuals with hearing impairment, regular physical activity and sport participation are most often positively associated with happiness and life satisfaction, whereas findings for stress are more variable and appear to be highly context sensitive (Göktepe, 2018; DeLuca & Rupp, 2022; Zhan, 2025). A consistent pattern across studies is that the psychosocial benefits of physical activity cannot be explained solely by quantitative indicators such as activity volume or energy expenditure. Rather, the social context of participation—including organized sport structures, group-based interaction, experiences of belonging, and access to social support—may be a key determinant of both the direction and magnitude of observed effects (Eime et al., 2013; DeLuca & Rupp, 2022). With respect to stress, evidence from the general population robustly supports exercise as a resource capable of attenuating the adverse consequences of stress and contributing to protective health outcomes; however, the relative scarcity of experimental and longitudinal designs in hearing-impaired samples limits causal inference and complicates efforts to delineate mechanisms and boundary conditions (Gerber & Pühse, 2009).

Within this framework, three primary implications emerge. First, promoting regular physical activity among individuals with hearing impairment appears to be a defensible, evidence-informed strategy for strengthening indicators of psychosocial well-being (Göktepe, 2018; Zhan, 2025). Second, organized sport participation may provide a particularly potent contextual platform—through structured social interaction, peer acceptance, and a strengthened sense of belonging—that can amplify the beneficial associations of physical activity with happiness and life satisfaction (Eime et al., 2013; DeLuca & Rupp, 2022). Third, to reduce heterogeneity in stress-related outcomes, future research should not only report the "dose" of physical activity (type, intensity, duration, and frequency) with greater precision, but also incorporate variables such as communication accessibility, social support, inclusivity of participation environments, and psychosocial resources as mediators and/or moderators within analytic models (Stults-Kolehmainen & Sinha, 2014; DeLuca & Rupp, 2022). Overall, regular physical activity and sport participation in individuals with hearing impairment should be conceptualized not merely as lifestyle behaviors that support physical health, but as multidimensional psychosocial resources with the potential to influence happiness, stress regulation, and life satisfaction (Diener, 1984; Zhan, 2025).

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Chapter 6

Promoting Physical Activity in School-Age Children

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Introduction

Childhood and adolescence are critical stages of accelerated physical, cognitive, and social development. Physical activity habits acquired during these periods are a fundamental factor in determining lifelong health behaviors. However, global data show that more than 80% of children worldwide do not meet these recommendations (World Health Organization [WHO], 2020). This situation increases the risk of many noncommunicable diseases such as obesity, type 2 diabetes, and cardiovascular disease. The World Health Organization recommends that children aged 5–17 engage in at least 60 minutes of moderate-to-vigorous physical activity per day. Indeed, regular physical activity has positive effects on cognitive function, mental health, musculoskeletal development, and obesity prevention (Hillman, Erickson, & Kramer, 2008; Janssen & LeBlanc, 2010). Duggal, Niemiro, Harridge, Simpson, and Lord (2019) reported that it reduces the risk of infection by strengthening the immune system, protects musculoskeletal health, and benefits osteoporosis. Studies conducted in Turkey have similarly shown that physical activity has significant effects on students' motivation, psychological resilience, and academic achievement. For example, Çifçi & Ballıkaya (2023) found a significant relationship between physical activity level and motivation in middle school students. Similarly, Demir & Çifçi (2020) reported that high school students who exercised regularly had higher levels of psychological resilience. As demonstrated in the studies cited, physical activity has multiple benefits for human health across all age groups, particularly children and adolescents. Therefore, it is crucial to encourage physical activity, especially among children and adolescents. Various theoretical models have been developed to understand and modify physical activity behaviors in order to foster the habit of physical activity. These models contribute significantly to the planning and implementation of physical activity interventions, particularly school-based ones

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(Lippke & Ziegelmann, 2008). Although there are many theoretical models in the literature on initiating and maintaining physical activity behavior, the theoretical framework of this study will address the ecological model, self-determination theory, and social cognitive theory.

1. Theoretical Framework

Ecological Model

Understanding the reasons behind physical activity behavior is a fundamental element in developing, improving, and sustaining public health interventions (Sallis, Prochaska, & Taylor, 2000). The ecological model also addresses the causes of health behaviors from a broad perspective and presents the most comprehensive framework for promoting physical activity (Bauman, Reis, Sallis, Wells, Loos, & Martin, 2012). It includes factors such as urban planning, transportation systems, parks, and walking areas—social and physical environments outside the health sector—that contribute to initiating and sustaining physical activity behavior. This model argues that physical activity behavior is shaped not only by individual preferences and characteristics but also by interpersonal, organizational, environmental, and political factors (Sallis, Owen, & Fisher, 2015). Individual behaviors are in constant interaction with the created social and physical environment. Changing the environment is more powerful and sustainable in changing behavior than individual interventions. The ecological model presents these interconnected factors, which are more effective at different times throughout life, under five main headings in Figure 1.

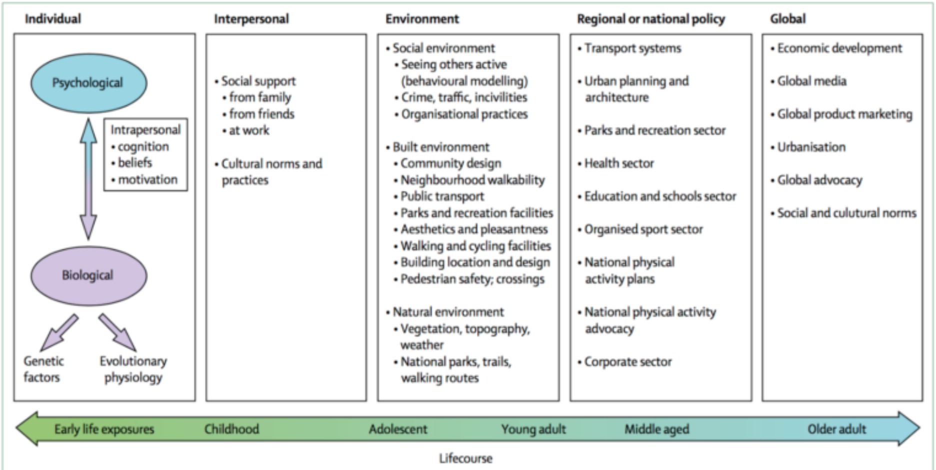

Figure 1: Ecological model (Sallis, Owen, & Fisher, 2015)

Self-Determination Theory (SDT)

Many factors in physical and social environments influence physical activity behaviors, and differences in physical activity behaviors are attributed to individual differences within social factors (Roberts, 2001). Self-determination theory is a theoretical approach that has gained popularity in attempting to understand the motivational factors that contribute to participation in physical activity (Biddle & Nigg, 2000). SDT focuses on why an individual participates in an activity and emphasizes the importance of types of motivation. It is a macro theory that addresses the individual and social factors that bring out different types of motivation in different environments and begins with the assumption that people have a natural tendency toward growth and development (Deci & Ryan, 2002). This theory has shown promising results in explaining school-aged students' physical activity motivation and behavior change and has received significant attention in the physical activity literature in recent years (Ryan & Deci, 2017).

Self-determination theory distinguishes between types of motivation (i.e., behavioral regulations) along a continuum ranging from intrinsic motivation, which is voluntary motivation, to amotivation, which indicates a lack of motivation (Ryan & Deci, 2017). Specifically, in physical education classes, intrinsic motivation is positively related to increased levels of physical activity (Lonsdale, Lester, Owen, White, Peralta, Kirwan, & Lubans, 2019), enjoyment and engagement in physical activity behavior (Vasconcellos, Parker, Hilland, Cinelli, Owen, Kapsal, & Lonsdale, 2019) and self-esteem, confidence, subjective well-being, and increased satisfaction with school (Ryan & Deci, 2020). In contrast, individuals with extrinsic motivation engage in an activity because they value the associated outcomes, such as public recognition and external rewards, rather than the activity itself (Deci & Ryan, 1985). In addition to intrinsic and extrinsic motivation, Deci and Ryan (1985) suggest that individuals may also be unmotivated toward an activity. Demotivation occurs when individuals experience a mismatch between their behaviors and outcomes and represent a complete lack of self-determination and volition regarding the targeted behavior. This situation is evident when individuals place no value on an activity or experience feelings of inadequacy and lack of control. Unfortunately, Ntoumanis (2005) reported that many students are unmotivated to participate in physical education activities.

Social Cognitive Theory (SCT)

The psychosocial mechanisms underlying individuals' engagement in physical activity behaviors at desired levels are important. Social Cognitive Theory (SCT) is one of the most effective psychosocial mechanisms. Developed by Bandura (1986), social cognitive theory proposes that behavior arises from the continuous interaction of the environment and individual cognitive factors. Social cognitive theory assumes that people's behaviors arise from the interaction of personal, behavioral, and environmental factors. Bandura (2004) also used this model to support the adoption of healthy behaviors and disease prevention. This theory suggests that cognitive processes, particularly self-efficacy, observational learning, and outcome expectations, are central to acquiring and maintaining health behaviors such as physical activity (Bandura, 2004). Self-efficacy is defined as an individual's belief in their ability to successfully perform a specific behavior, and research consistently shows that it is one of the strongest predictors of participation in physical activity (Bauman, Sallis, Dzewaltowski, & Owen, 2002). However, individuals' outcome expectations regarding the positive health outcomes of physical activity (e.g., improved mood or weight control) also significantly influence behavioral intention (Conner & Norman, 2005). These core components of Social Cognitive Theory suggest that physical activity behaviors are based not only on individual willpower but also on cognitive perceptions and interaction with the social environment.

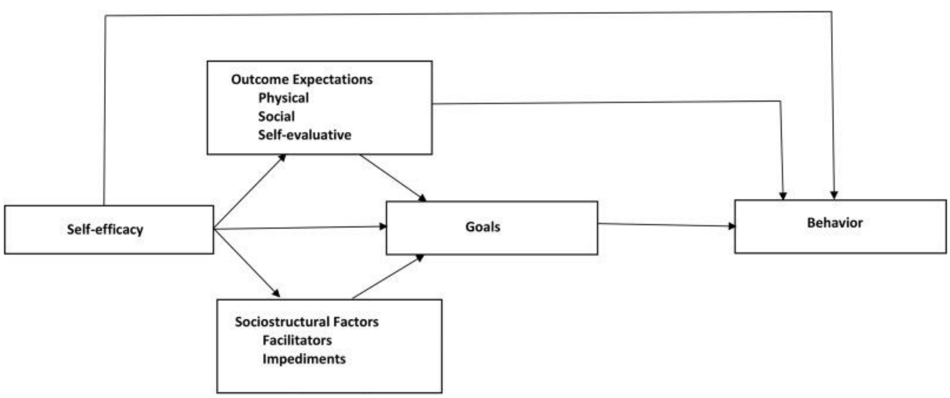

Figure 2. Social cognitive theory model of health behavior (Bandura, 2004)

2. Physical Activity Interventions

Models used in the literature to explain physical activity behaviors indicate that multi-component interventions are effective in promoting physical activity among children (Van Sluijs, McMinn, & Griffin, 2007). Physical activity interventions in the literature generally focus on three main settings: family and parent-focused interventions, school-based interventions, and community and environmental interventions. However, with the integration of technology into human life in recent years, technology and wearable device-focused physical activity interventions have become popular.

Family and Parent-Focused Interventions

Parents can strongly influence their children's physical activity behaviors through role modeling and direct participation, and these effects can continue beyond adolescence (Norton, Froelicher, Waters, & Carrieri-Kohlman, 2003). Trost and Loprinzi (2011) noted that parents serving as role models and actively participating with their children directly affected children's activity levels. The family is the closest micro-social structure that determines children's daily routine behaviors, serves as a role model for them, and creates physical opportunities (Bronfenbrenner, 1992). Parental support, direct help from parents, and opportunities to exercise have been consistently associated with physical activity during adolescence (Sallis, Prochaska, & Taylor, 2000). Çifçi and Ballıkaya (2023), who worked with Turkish middle school students, reported that parental support and motivational climate increased physical activity behavior. A review of the literature shows that parent education programs, home environment modifications, involving the family in physical activity together, and family-based multi-component interventions are effective in encouraging children and adolescents to engage in and maintain physical activity. Researchers have determined that educational programs for parents that increase awareness of physical activity and healthy living lead to significant increases in the physical activity levels of children and adolescents. Ruedl, Niedermeier, Wimmer, Ploner, Pocecco, Cocca, and Greier (2021) found that educating parents contributed to the long-term physical fitness and physical activity of elementary school students. Home environment modifications also directly impact children's physical activity levels. Maitland, Stratton, Foster, Braham, and Rosenberg (2013) reported that the home environment has a significant impact on children's physical activities. Another intervention is involving the family in physical activity together. Yao and Rhodes (2015) determined that physical activity activities performed by the family positively affect children's attitudes toward physical activity. Demir (2020) reported that active video games, such as exergames, play a role in increasing family activities and encourage physical activity by enhancing communication and interaction between children and parents. Multi-component interventions centered on the family create stronger effects compared to individual-focused interventions.

School-Based Interventions

Schools are fundamental settings where children and adolescents spend most of their time and where opportunities for organized activities can be provided. Therefore, they are ideal settings for implementing physical activity interventions (Kelso, Linder, Reimers, Klug, Alesi, Scifo, & Demetriou, 2020). Stone, McKenzie, Welk, and Booth (1998) argued that school-based interventions are beneficial because schools provide the necessary infrastructure. Many researchers have also demonstrated that school-based interventions are effective in initiating and sustaining physical activity. For example, van de Kop, van Kernebeek, Otten, Toussaint, and Verhoeff (2019) reported in their meta-analysis that school-based physical activity interventions increased physical activity among adolescents.

Improving the quality of physical education classes is at the forefront of effective school-based physical activity interventions. Physical education classes in schools are particularly important for supporting children's active lifestyles and overall well-being through participation in physical activity (Jevdjevic, Arbour-Nicitopoulos, Martin Ginis, and Voss, 2025). In Turkey, physical education curricula include standards aimed at promoting an active lifestyle through regular physical activity and sports. Training physical education teachers to improve lesson quality and student participation is important for school-based interventions. Recess is seen as a critical target for school-based interventions. Interventions such as organizing school playgrounds, adding equipment to these areas, and extending recess times support physical activity behaviors during breaks. Research has found that recess duration, playground markings, designation of physical activity areas, and sports equipment were positively associated with physical activity (Suga, da Silva, Brey, Guerra, & Rodriguez-Añez, 2021). Eather, Morgan, and Lubans (2013) found that social support for physical activity provided by teachers contributed to the development of physical activity in children. Increasing the physical literacy of students, i.e., children and adolescents, should also be considered an effective intervention strategy. Weir, Pringle, and Roscoe (2024) stated that developing physical literacy is an important factor in supporting the physical development of children and adolescents and encouraging physical activity. Finally, structured extracurricular activities offered in preschool and after-school settings provide students with opportunities for physical activity. These activities not only ensure that children and adolescents engage in physical activity but also lead to them continuing these activities and pursuits in the future. Structured programs offered before and after school provide safe and supervised physical activity opportunities for children. Sports clubs, dance groups, and recreational play activities fall into this category.

Social and Environmental Interventions

The relationship between environmental conditions and health-related behaviors has been clearly emphasized in social and behavioral science models and theories (Bandura, 1986; McLeroy, Bibeau, Steckler, & Glanz, 1988). Public health research, in particular, has reported that social and environmental interventions are factors that need to be addressed in promoting physical activity behavior (Schmid, Pratt, & Howze, 1995). Physical activity is a behavior shaped by the social environment because many of the activities individuals engage in take place within the boundaries of the family, community, and neighborhood (Li, Fisher, Bauman, Ory, Chodzko-Zajko, Harmer, & Cleveland, 2005). Hünük, Özdemir, Yıldırım, & Aşçı (2013) reported in their study that the social support children and adolescents receive from their parents, especially their mothers, is a determining factor in their participation in physical activity.

Environmental factors are a powerful factor supporting behavioral change in effective public health approaches to promoting physical activity (Schmid Pratt & Howze, 1995). The ecological model also emphasizes the physical environment and shows that it triggers physical activity behavior. Sallis, Owen, and Fisher (2015) state that having safe and accessible facilities for physical activity and sports increases the likelihood of engaging in such activities. This paves the way for children and adolescents to become more physically active individuals.

Technology and Wearable Device-Based Interventions

Technological innovations offer significant opportunities for promoting physical activity. Web-based interventions, in particular, have the potential to promote physical activity behavior across all age groups (Gilson, 2013). Dirkin (1994) also reported that physical activity is an effective determinant as an area where participants can design their activities, track their progress over time, and benefit from the services of counselors either synchronously or asynchronously. Pedometer, smartwatches, internet-based fitness applications, and exercise games called exergaming or gamercising provide instant feedback, encouraging children and adolescents to engage in physical activity and contributing to the achievement of their goals (Biddle, Gorely, Pearson, & Bull, 2011; Demir & Akın, 2020). Furthermore, Demir and Akın (2018) reported in a separate study on children that exergames have benefits in improving children's balance skills. Virtual reality games involving movement, such as exergaming, can increase the participation of sedentary children by making physical activity fun. The literature also reports that smartphones are valuable for developing and improving physical activity levels by measuring them in real time and providing feedback (Intille, Lester, Sallis, & Duncan, 2012).

Conclusion

Childhood and adolescence are critical periods for maintaining physical activity behavior. Appropriate interventions and experiences during this period are decisive in ensuring that they become active individuals in their future lives. Again, the promotion of physical activity is a multidimensional process that can be strengthened not only through individual efforts but also through coordinated interventions by the family, school, and social environment. This multidimensional approach plays a fundamental role in helping children and adolescents develop healthy lifestyle habits. In this context, schools occupy a central position in promoting physical activity, as they are places where children and adolescents spend a significant portion of their daily lives. School-based interventions make important contributions to supporting physical activity behavior by improving the quality of physical education classes, increasing opportunities for physical activity during and outside of class, implementing active recess practices, organizing extracurricular sports activities, and creating movement-friendly school environments. Furthermore, different theoretical models provide guidance for better understanding and effectively supporting physical activity behavior. While theoretical models provide a fundamental perspective for explaining the underlying processes of physical activity behavior, interventions contribute to making this behavior permanent and sustainable through practical applications. Strengthening these comprehensive efforts will form an important foundation for raising healthier and more active generations in the future. Addressing the issue with a comprehensive understanding is important for building a society that is more active and therefore healthier throughout life.

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