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REVIEW ARTICLE

β-adrenergic agonists and β-antagonists in sport performance: a narrative synthesis of pharmacological effects and anti-doping implications

Tatiana Chiriac[1*], Ina Pogonea[1], Tatiana Timercan[2], Artiom Jucov [3,4], Silvia Stratulat[2], Alisa Tăbîrță[5], Victoria Chihai[5]

[1]Department of Pharmacology and Clinical Pharmacology, *Nicolae Testemițanu* State University of Medicine and Pharmacy, Chișinău, Republic of Moldova
[2]Department of Biochemistry and Clinical Biochemistry, *Nicolae Testemițanu* State University of Medicine and Pharmacy, Chișinău, Republic of Moldova
[3]Department of Family Medicine, *Nicolae Testemițanu* State University of Medicine and Pharmacy, Chișinău, Republic of Moldova
[4]National Anti-Doping Agency, Chișinău, Republic of Moldova
[5]Department of Medical Rehabilitation, Physical Medicine and Manual Therapy, *Nicolae Testemițanu* State University of Medicine and Pharmacy, Chișinău, Republic of Moldova

ABSTRACT

Introduction. In the context of increasingly intense athletic competition, athletes are motivated to enhance their performance through various methods, including the use of pharmacological substances that act on the adrenergic system. Among these, β2-adrenergic agonists are employed for their metabolic effects and their role in increasing endurance, whereas β-adrenergic antagonists are used in precision sports to reduce tremor and control anxiety. Both classes of substances present potential benefits as well as health risks, and are subject to strict regulations in high-performance sports.

Material and methods. A theoretical study was conducted based on the analysis of specialized scientific literature, aiming to evaluate the impact of β2-adrenergic agonists and β-adrenergic antagonists on athletic performance. Additionally, the current regulations of the World Anti-Doping Agency (WADA) were analyzed.

Results. β2-adrenergic agonists may contribute to the stimulation of muscle protein synthesis, enhancement of energy metabolism, and delay in the onset of fatigue. However, their use is associated with significant cardiovascular and metabolic side effects. β-adrenergic antagonists are effective in reducing tremor and sympathetic activation in precision sports but may decrease overall exercise capacity and induce bradycardia or chronic fatigue. Improper use of these substances can lead to severe sanctions in the context of athletic competitions.

Conclusions. Although β2-adrenergic agonists and β-adrenergic antagonists may offer certain advantages depending on the specific nature of the sport, their use must be strictly medically regulated and comply with anti-doping standards. Careful evaluation of the risk-benefit ratio is essential for safeguarding athletes' health and preserving the integrity of competition.

Keywords: β-adrenoreceptors, β-adrenergic agonists, clenbuterol, salbutamol, β-adrenergic antagonists, propranolol.

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[*]**Corresponding author**: **Tatiana Chiriac**, assistant professor, Department of Pharmacology and Clinical Pharmacology, *Nicolae Testemițanu* State University of Medicine and Pharmacy, Chisinau, Republic of Moldova,
e-mail: tatiana.chiriac@usmf.md,

Key messages

What is not yet known about the issue addressed in the submitted manuscript

Although β2-adrenergic agonists and β-adrenergic antagonists are frequently used in athletic contexts, their actual impact on performance in trained athletes remains only partially elucidated. Direct comparisons of their effects based on the type of exer-

Authors' ORCID IDs
Tatiana Chiriac – https://orcid.org/0000-0003-4551-9677
Ina Pogonea – https://orcid.org/0000-0001-6432-9655
Tatiana Timercan – https://orcid.org/0000-0003-2313-8654
Artiom Jucov – https://orcid.org/0000-0003-4664-8323
Silvia Stratulat – https://orcid.org/0000-0003-0985-307X
Alisa Tăbîrță – https://orcid.org/0000-0002-7835-2271
Victoria Chihai – https://orcid.org/0000-0003-1399-7009

tion and the pharmacological characteristics of these substances are still limited in the specialized literature.

The research hypothesis

To evaluate the impact of β-adrenergics on athletic performance, along with the associated health risks, cardiovascular and metabolic side effects, and the legal and ethical ramifications concerning doping.

The novelty added by the manuscript to the already published scientific literature

The research provides a comprehensive and in-depth understanding of how β-adrenergics influence various aspects of metabolism and sports performance, explains the associated risks, and promotes the responsible use of these substances.

Introduction

Sport performance represents a central objective in today's competitive culture, being determined by a range of physiological, psychological, and technological factors.

Physiological factors include cardiovascular and respiratory capacity, muscle mass and strength, energy metabolism efficiency, and hormonal balance. Psychological factors encompass aspects such as motivation, stress tolerance, concentration, and mental resilience. Technological factors involve the use of advanced equipment, modern performance monitoring techniques, and personalized recovery and nutrition interventions. Within this integrative framework of performance optimization, an increasing number of athletes resort to pharmacologically active substances that can directly or indirectly influence cardiovascular, metabolic, neuromuscular, and central nervous system functions involved in athletic exertion.

Among these, drugs acting on the β-adrenergic system are particularly attractive in the context of high-performance sport. The use of pharmacological substances by athletes as agonists or antagonists of β-adrenergic receptors is a current concern that requires careful evaluation of the benefit-risk ratio [1], in accordance with existing anti-doping regulations. The administration of these compounds must be based solely on a justified medical indication and carried out under specialist supervision, respecting both their mechanism of action on the β-adrenergic system [1] and the regulatory framework governing athletic performance [2].

β2-adrenergic receptor agonists (β2-adrenomimetics) are used therapeutically for their bronchodilator effects, but in sports they have gained notoriety for their anabolic potential, ability to stimulate protein synthesis, and capacity to increase metabolic rate through enhanced lipolysis and glycogenolysis. The use of these substances can lead to the rapid mobilization of energy substrates, delaying the onset of fatigue and increasing muscular endurance during sustained effort. However, their use is associated with significant side effects, such as tachycardia, hypokalemia, left ventricular hypertrophy, and mitochondrial toxicity [3]. Furthermore, systemic administration of β2 agonists is considered doping and is prohibited under World Anti-Doping Agency regulations, except for specified inhalation doses [2].

In comparison, beta-adrenoblockers (β-adrenoblockers), which inhibit the activation of β1 and/or β2-adrenergic receptors, are used in sports that require precision, fine coordination, and emotional control, such as shooting sports or martial arts. These medications reduce sympathetic activity [1], inducing bradycardia and diminishing physiological tremor, thereby facilitating focus and stability in static sports. Although they exert an ergolytic effect in endurance sports, in precision sports they may provide a considerable advantage, which is why their use is restricted by WADA in selected competitions [2].

Recent literature highlights conflicting perspectives regarding the role of these substances in optimizing athletic performance. While some studies support their efficacy in specific physiological contexts, others emphasize the significant health risks and the negative impact on competitive equity [4]. The topic thus remains relevant and controversial, given the lack of clear scientific consensus and the often-divided opinions–factors which justify the need for further analysis.

Material and methods

This study was designed as a narrative review of specialized scientific literature, aiming to analyze the pharmacological mechanisms, physiological effects, and regulatory aspects of β2-adrenergic agonists and beta-adrenoblockers in high-performance sport. The bibliographic search was conducted using electronic databases: PubMed, Scopus, Elsevier, BMJ, Springer, Web of Science, and Google Scholar, which included peer-reviewed scientific articles, clinical studies, systematic reviews, meta-analyses, and official guidelines (WADA, EMA), as well as works detailing the pharmacological mechanisms of action, medical indications, and physiologically relevant effects in the athletic context. The data were thematically classified into two categories: β2-agonists and β-adrenergic antagonists, and comparisons were made based on the type of effects on athletic performance (Table 1).

Statistical methods were not applied, as the study did not include quantitative analysis or meta-analysis. The work is

based on a qualitative and comparative synthesis, with emphasis on the pharmacological significance and clinical relevance of the findings.

Results

The qualitative analysis of the specialized literature revealed a significant number of findings regarding the impact of β2-agonists on athletic performance. The main hypothesis, that these substances could contribute to performance enhancement through metabolic and neuromuscular mechanisms, was supported by several lines of research.

a) Stimulation of muscle protein synthesis

The use of β2-agonists leads to an increase in protein synthesis in skeletal muscle, contributing to hypertrophy and muscle recovery, especially during strength training. This effect is genetically mediated through the activation of PGC-1α and other pathways involved in myogenesis [5-11].

b) Reduction of protein degradation and mitochondrial protection

β2-agonists not only stimulate protein synthesis but also reduce the rate of muscle protein degradation. Additionally, they increase mitochondrial protein synthesis and the expression of PGC-1α mRNA, which is involved in mitochondrial biogenesis [12-16].

c) Increase in energy metabolism

Activation of β2 receptors leads to the mobilization of fatty acids through lipolysis, increased glycogenolysis, and stimulation of metabolic pathways for ATP production. These mechanisms support intense and prolonged physical effort [8, 17-21].

d) Improvement of fatigue resistance

Increased resistance to fatigue is explained by central nervous system stimulation, enhanced muscle perfusion, mobilization of energy resources, and a reduced perception of pain. All these effects contribute to sustaining long-term performance [13, 14, 18, 22-24].

e) Modulation of muscle contraction

β2-agonists produce positive ionotropic and lusitropic effects on slow-twitch muscle fibers without significantly altering myofibrillar sensitivity to Ca^{2+}. These effects occur only at high concentrations of β-adrenergic agonists [25-29].

f) Reported limitations and adverse effects

Prolonged use or high doses are associated with severe adverse effects, such as tachycardia, mitochondrial toxicity, cardiac impairment, and metabolic disorders. The risks are particularly pronounced in the case of clenbuterol [18, 30-32].

g) Confirmation of anti-doping regulations

According to WADA 2025, most β2-agonists are prohibited, with some exceptions for inhaled forms. Explicit guidelines are provided for salbutamol, formoterol, and vilanterol [2].

After analyzing the pharmacological and physiological effects of β2-adrenergic agonists on athletic performance, data regarding β-adrenergic antagonists were also synthesized, especially in the context of sports requiring precision, fine coordination, and emotional control. These substances, by blocking β1 and/or β2 receptors, reduce sympathetic activity [3], induce bradycardia, and attenuate physiological tremor, thereby contributing to performance stabilization under competitive stress conditions.

a) Reduction of tremor and anxiety

Propranolol is used off-label (outside of the approved indication) for the management of performance anxiety, usually being administered approximately one hour before a sports event. It reduces tremor and associated somatic symptoms such as tachycardia and palpitations, and is frequently used in sports contexts [33]. A recent randomized, placebo-controlled clinical study demonstrated that propranolol exerts a general reduction effect on neuronal activity in the motor cortex, regardless of the specific tremor context. This finding indicates that propranolol's action is not limited to peripheral effects – such as the reduction of heart rate or muscular tremor through β-adrenergic receptor blockade – but also involves a central, neurophysiological component. More precisely, the drug directly influences the reactivity of neuronal networks in the motor cortex, an essential area for the planning and execution of voluntary movements. This central mechanism contributes to the stabilization of fine motor control and can explain the efficacy of propranolol in reducing tremor both in neurological disorders (such as Parkinson's disease) and in performance anxiety situations, where excessive activation of the nervous system may interfere with motor precision [34].

b) Efficacy in precision sports

In contrast to endurance sports, where β-adrenergic antagonists may negatively affect performance, in precision sports they can bring significant benefits.

Precision sports like shooting, archery, or billiards require fine motor control and high psychophysiological stability – factors that can be positively influenced by blocking adrenergic receptors. It is considered that the beneficial effect of metoprolol in this context derives from its ability to selectively block β1-adrenergic receptors. By reducing sympathetic activity, metoprolol contributes to the attenuation of physiological tremor and to the stabilization of fine movements, which are essential for precision. The study conducted by Kruse et al. (1986) showed an increase in pistol shooting performance by approximately 13% compared to placebo, in the absence of significant changes in monitored cardiovascular parameters (such as heart rate or oxygen saturation), suggesting that the observed benefits are more likely attributed to the neuromuscular control of tremor rather than a hemodynamic effect. This mechanism confers a specific therapeutic value to metoprolol in static sports that require coordination and precision [35]. However, the efficacy of β-adrenergic antagonists can vary considerably depending on the type of sporting discipline and the pharmacological profile of the administered substance. Similar to metoprolol in sport shooting, the use of propranolol or bisoprolol has also been analyzed in archery. Nevertheless, the study conducted by Ergen et al. (2021) did not demonstrate significant performance improvements under simulated conditions, suggesting that the favorable effect of

β-adrenergic antagonists may strictly depend on the type of activity, dosage, and the application context [36].

c) Impact in endurance sports

Unlike precision sports, where β-adrenergic antagonists may have a favorable effect on fine motor control, in endurance disciplines their effects are predominantly negative. β-adrenergic antagonists reduce heart rate and cardiac output during physical exertion, which limits tissue oxygenation capacity and may lead to an increased perception of fatigue. As a result, oxidative performance declines in dynamic aerobic activities like running and cycling. The study conducted by Priel et al. (2021) confirms these observations, highlighting an impairment of cardiorespiratory parameters under the influence of β-adrenergic antagonists, along with reduced exercise tolerance compared to subjects not receiving treatment [37].

d) Adverse effects and contraindications

The use of β-adrenergic antagonists, particularly non-selective ones, is frequently associated with adverse reactions such as bradycardia, arterial hypotension, persistent fatigue, bronchospasm, and an increased risk of depressive symptoms [1, 3]. These effects can become limiting for professional athletes, affecting both physical performance capacity and their overall psychological state. Moreover, recent guidelines emphasize the risks associated with the use of these medications in certain comorbidities, such as bronchial asthma, diabetes mellitus (due to the risk of masking hypoglycemia symptoms), or slow-onset hypoglycemic episodes that are difficult to detect. These contraindications highlight the need for careful patient selection and close monitoring of treatment effects in the context of sports performance [38].

Table 1. Comparison between β2-adrenergic agonists and β-adrenergic antagonists in professional sports

Characteristics	β2-adrenergic agonists	β-adrenergic antagonists
Main mechanism	Agonistic effect on β2 receptors → sympathetic stimulation	Antagonistic effect on β1/β2 receptors → sympathetic inhibition
Main effects	Bronchodilation, stimulation of protein metabolism, mobilization of energy	Decrease in heart rate, tremor reduction, anxiolytic effect
Targeted sports	Endurance sports, strength competitions, bodybuilding	Precision sports: shooting sports, cue sports, golf
Possible benefits	Increase in muscle mass, delayed onset of fatigue	Improvement of fine motor control
Risks/adverse effects	Tachycardia, cardiotoxicity, hypokalemia	Bradycardia, fatigue, bronchospasm, depression
Anti-doping status (WADA)	Systemic forms prohibited (except for metered-dose inhalers)	Prohibited in certain precision sports
Examples	Clenbuterol, salbutamol, formoterol	Propranolol, metoprolol, bisoprolol

Note: *WADA – World Anti-Doping Agency*

Discussion

The analysis of specialized literature highlights that, while β2-adrenergic agonists show positive effects in animal experiments and occasionally in humans, the evidence regarding performance improvement in trained athletes remains limited [39]. These substances mimic the action of catecholamines on adrenergic receptors, being frequently used in the treatment of asthma and other respiratory diseases [40], but also with the aim of increasing muscle mass and physical performance.

According to the 2025 World Anti-Doping Code, the use of β2-adrenergic agonists is prohibited, except for certain inhaled doses of salbutamol, salmeterol, formoterol, and vilanterol, accompanied by a Therapeutic Use Exemption.

β2-adrenergic agonists act by:

- ***Enhancing physical performance*** by increasing heart rate, contractility, and inducing bronchial dilation [41].
- ***Stimulating protein synthesis***, leading to muscle growth and improved recovery [9].
- ***Accelerating energy metabolism*** by promoting fat and glucose mobilization.
- ***Influencing cognitive functions and mood*** by acting on central β-adrenoreceptors.

The anabolic effect of β2-agonists is supported by the enhancement of protein synthesis, the redistribution of body composition ("repartitioning effect"), and the influence on genes involved in myogenesis [5-8, 10, 11].

At the mitochondrial level, β2-agonists can stimulate the expression of PGC-1α, which is involved in mitochondrial biogenesis [13-16]. An increase in mitochondrial and muscle protein synthesis has been observed following 7 days of administration [12], but validation of these results in athletes requires further investigation, as currently available evidence comes predominantly from animal models.

At the metabolic level, β2-agonists increase the release of fatty acids through activation of hormone-sensitive lipase (HSL), stimulate glycogenolysis, and contribute to sustaining intense physical effort [17, 21]. Clenbuterol use is also associated with severe adverse effects (tachycardia, hypokalemia, chest pain, myocardial injury) [18, 30, 32].

Regarding fatigue, β2-agonists can stimulate the release of neurotransmitters (dopamine, noradrenaline), reduce pain perception, and improve muscle blood flow [22]. Although these effects may enhance sustained physical effort, the benefits in humans vary.

Muscle contractility is influenced by β2-agonists in slow-twitch (type I) fibers by improving relaxation and Ca^{2+} handling, but these effects are not sustained at physiological concentrations [26-29]. In cases of chronic administration, the increased level of cAMP stimulates adenosine production, which may antagonize the positive effects [25, 27].

In conclusion, the use of β2-adrenergic agonists may provide metabolic and muscular benefits but involves con-

siderable systemic risks, especially at high doses or with prolonged administration. Evidence for their effectiveness in sports remains inconsistent, requiring further research alongside compliance with anti-doping regulations.

β-adrenergic antagonists offer a clear pharmacological contrast, acting as antagonists of β1 and/or β2 receptors. In precision sports, their benefits lie in reducing physiological tremor, controlling anxiety, and inducing a state of calm necessary under competitive pressure. Their effectiveness is well documented, with performance improvements of up to 13% in sports such as competitive shooting [35]. However, these effects can vary significantly depending on the type of sport discipline, dose, and the selectivity of the β-adrenergic antagonists used [36].

On the other hand, in endurance sports, β-adrenergic antagonists can have an ergolytic effect. By reducing heart rate and cardiac output, they limit the capacity for sustained effort and increase the sensation of fatigue [37]. These effects are relevant in activities such as running and cycling, where cardiorespiratory efficiency is essential.

There are several adverse effects: bradycardia, hypotension, chronic fatigue, bronchospasm (especially with non-selective beta-blockers), and risk of depression. β-adrenergic antagonists can also mask symptoms of hypoglycemia, which poses an additional risk for athletes with diabetes, as they delay the recognition of a dangerous drop in blood glucose levels [38]. Contraindications include severe asthma, atrioventricular block, and certain forms of heart failure [1, 3].

Therefore, the inclusion of β-adrenergic antagonists in the analysis of sports performance highlights a complex reality: although they can offer clear advantages in precision sports, their use is limited by significant side effects and anti-doping regulations. An individualized assessment based on the type of activity, the athlete's physiological profile, and medical context is essential for an ethical and safe decision regarding the use of these pharmaceutical substances.

Conclusions

This study provides an integrative perspective on the pharmacological and physiological implications of β2-adrenergic agonists and β-adrenergic antagonists in sports performance. By synthesizing current scientific evidence and regulatory guidelines, it underscores the importance of a nuanced, discipline-specific approach to these substances. The added value lies in clarifying their differential impact depending on the sport type, offering a scientifically grounded basis for informed decisions in both clinical and anti-doping contexts.

Note: Parts of this review have been adapted and extended from previously published work (Pogonea I. et al., Farmacist.ro, 2025), with additional analysis regarding β-adrenergic antagonists [42].

Competing interests

None declared.

Authors' contributions

IP – conceptualization, designed the study, critically revised the manuscript. TC – conceptualization, writing original draft. TT – designed the study, critically revised the manuscript. AJ – validation, project administration. SS – supervision, data curation. AT – data collection and analysis. VC – data analysis and interpretation. All the authors approved the final version of the manuscript.

Ethics approval

Not needed for this study.

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