International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Scholarly Publisher
RS Global Sp. z O.O.
ISNI: 0000 0004 8495 2390

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ARTICLE TITLE	BETA-BLOCKERS IN SPORT: PHYSIOLOGICAL EFFECTS, PERFORMANCE IMPLICATIONS AND REGULATORY PERSPECTIVES
DOI	https://doi.org/10.31435/ijitss.4(48).2025.4356
RECEIVED	14 October 2025
ACCEPTED	10 December 2025
PUBLISHED	19 December 2025
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BETA-BLOCKERS IN SPORT: PHYSIOLOGICAL EFFECTS, PERFORMANCE IMPLICATIONS AND REGULATORY PERSPECTIVES

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ABSTRACT

Introduction: Beta-blockers are a pharmacological class widely used in cardiovascular and anxiety-related conditions. Their ability to reduce heart rate, reduce physiological tremor and attenuate sympathetic arousal has led to increasing interest regarding their use in sport. While beta-blockers impair endurance performance, they may enhance precision and emotional stability in sports requiring fine motor control. This has resulted in selective regulation by anti-doping authorities.
Aim of the study: The aim of this article was to review the current evidence on physiological effects of beta-blockers in athletes and to evaluate their sport-specific implications, including their relevance to anti-doping regulations.
Methods and Materials: Literature was reviewed using PubMed, Scopus and Google Scholar databases, focusing primarily on experimental human studies, controlled trials and mechanistic analyses investigating beta-blocker pharmacology and athletic performance. Key search terms included: "beta-blockers", "sport performance", "precision sports", "beta receptors", and "doping".
Conclusion: Evidence indicates that beta-blockers exert mixed performance effects depending on sport characteristics. They consistently reduce endurance capacity by limiting cardiac output and metabolic efficiency, yet can benefit athletes in precision disciplines through tremor suppression and decreased somatic anxiety. These sport-specific effects justify the selective prohibition adopted by the World Anti-Doping Agency. Further research is needed to clarify individual variability in response and to refine regulatory approaches.

KEYWORDS

Beta-Blockers, Sport Performance, Doping, Precision Sports, WADA

CITATION

Szymon Rudawski, Magdalena Zięba, Magdalena Morytko, Maja Elertowicz, Mikołaj Moskwa, Patrycja Herod, Aleksandra Wójciak, Kateryna Shtohryn, Hubert Gugulski. (2025). Beta-Blockers in Sport: Physiological Effects, Performance Implications and Regulatory Perspectives. *International Journal of Innovative Technologies in Social Science*. 4(48). doi: 10.31435/ijitss.4(48).2025.4356

1.Introduction

The β-adrenergic system plays a central role in regulating cardiovascular, respiratory, metabolic, and psychophysiological responses to stress, with β_1, β_2, and β_3 receptors mediating key adaptations during exercise, including increased heart rate, cardiac contractility, bronchodilation, and energy mobilization (Queen & Ferro, 2006; Antonelli et al., 2012; Johnson, 1998). Because athletic performance depends heavily on efficient sympathetic activation, pharmacological agents that modulate this system have long attracted attention within sports science and sports regulation (Ljungqvist, 2017).

Beta-blockers, a pharmacological class widely used in cardiovascular medicine for the treatment of hypertension, arrhythmias, ischemic heart disease, and anxiety-related somatic symptoms, exert their effects through antagonism of β-adrenergic receptors (do Vale et al., 2019; Oliver et al., 2019). By decreasing heart rate, reducing tremor amplitude, and suppressing sympathetic arousal, they can influence both physical and psychomotor performance parameters relevant to sport (Tsai et al., 2015; Frei & Truong, 2022). Although beta-blockers do not possess classical ergogenic properties associated with anabolic steroids or stimulants (García-Arnés et al., 2022; Wenbo & Yan, 2023; Docherty, 2008), their capacity to enhance fine motor control and psychophysiological stability has raised concerns regarding unfair performance enhancement in sports requiring high precision (Davis et al., 2008; Ergen et al., 2021; Kruse et al., 1986).

In recognition of the sport-specific ergogenic potential of beta-blockers, the World Anti-Doping Agency (WADA) has designated them as prohibited substances in-competition for selected precision-based disciplines, including shooting, archery, billiards, and certain winter sports where fine motor stability is decisive (World Anti-Doping Agency, 2024). This targeted prohibition reflects the principle that a substance should be banned when it can provide a performance advantage in a particular context, even if it does not enhance performance globally across all sports. At the same time, WADA permits Therapeutic Use Exemptions (TUEs) for athletes

requiring beta-blockers for legitimate medical reasons, creating a regulatory framework that must balance athlete safety, medical necessity, and competitive integrity (World Anti-Doping Agency, 2018).

This review synthesizes current evidence on β-adrenergic physiology, beta-blocker pharmacology, their effects on athletic performance across various sport types, and the regulatory considerations that shape their controlled use in modern sport.

2. Beta-Adrenergic Receptors and Physiological Mechanisms

The β-adrenergic system constitutes a fundamental component of the sympathetic nervous system, enabling rapid physiological adjustments during physical and psychological stress. Its actions are mediated by β_1-, β_2-, and β_3-adrenergic receptors, members of the G-protein-coupled receptor (GPCR) family, which respond to endogenous catecholamines such as norepinephrine and epinephrine (Johnson, 1998; do Vale et al., 2019). Each receptor subtype exhibits distinct patterns of tissue distribution, intracellular signaling, and physiological function, together shaping the body's capacity to regulate cardiovascular output, ventilation, metabolic substrate utilization, and neuromuscular stability during exercise (Wallukat, 2002).

2.1 Receptor Subtypes and Tissue Distribution

β_1-receptors are predominantly expressed in cardiac tissue, particularly within the sinoatrial node, atrioventricular node, and ventricular myocardium. Activation leads to increased heart rate, enhanced conduction velocity, and elevated contractile force (Motiejunaite et al., 2021).

β_2-receptors are primarily located in bronchial smooth muscle, peripheral vasculature, and skeletal muscle fibers. Their activation induces bronchodilation, vasodilation in skeletal muscle, and modulation of potassium handling in myocytes mechanisms crucial for optimizing oxygen delivery and preventing fatigue during sustained physical activity (Brodde & Leineweber, 2005).

β_3-receptors, though less prominent in sport physiology, play roles in adipose tissue lipolysis and energy metabolism. Their contribution to acute exercise performance is comparatively small but may affect longer-term metabolic adaptations (Cero et al., 2021).

2.2 Physiological Responses During Exercise

During physical exertion, sympathetic activation is essential for maintaining cardiovascular stability and optimizing performance. Stimulation of β_1-receptors drives increases in heart rate and stroke volume, raising cardiac output to deliver oxygen and nutrients to working muscles. Simultaneously, β_2-mediated bronchodilation facilitates increased ventilation, while vasodilation improves perfusion of active muscle groups (Van Baak, 1988).

Catecholamine-mediated effects also influence metabolic pathways. β-adrenergic activation enhances lipolysis, maintains plasma glucose availability, and promotes mobilization of free fatty acids-critical substrates for sustained aerobic exercise. Additionally, β_2-receptor stimulation affects neuromuscular coordination by modulating tremor amplitude; physiological tremor tends to increase under heightened sympathetic drive, potentially impairing fine motor control in tasks requiring precision.

2.3 Psychophysiological Role in Performance

Beyond physiological functions, β-adrenergic activation is integral to psychomotor performance. Emotional arousal-such as pre-competition anxiety triggers sympathetic discharge, manifesting in increased heart rate, muscle tension, tremor, and reduced steadiness. These effects, while potentially beneficial in power or endurance events, can hinder performance in precision sports. Studies investigating stage fright and public performance anxiety have shown that suppression of β-mediated somatic symptoms significantly improves task execution, offering a mechanistic parallel to sport contexts involving high-pressure environments (Brantigan et al., 1982).

3. Physiological and Sport-Specific Effects of Beta-Blockers

Beta-blockers exert a broad range of physiological effects that influence sport performance, and much of our understanding of these mechanisms stems directly from experimental and clinical studies (Taddei et al., 2024). Classical and contemporary research shows that these drugs can markedly impair endurance performance while, under specific conditions, providing advantages in precision sports.

The most thoroughly documented effects of beta-blockers involve the cardiovascular system. Early controlled research by Cléroux et al., 1989 demonstrated that both β_1-selective and non-selective beta-blockers significantly reduce exercise tolerance and limit aerobic performance. Although VO_2max was not directly measured, reductions in exercise duration and blunted cardiovascular responses confirm that beta-blockade depresses physical capacity during submaximal and maximal effort. In a study by Tesch, 1985 further

emphasized that reductions in maximal heart rate, often ranging from 20 to 35 beats per minute, directly constrain endurance performance, leading to earlier fatigue and diminished ability to sustain high workloads. These findings have been consistently replicated, establishing beta-blockers as ergolytic in endurance sports such as cycling, running, rowing, and cross-country skiing.

Respiratory and ventilatory consequences reinforce this impairment. Non-selective beta-blockers, through antagonism of β_2 receptors, can induce varying degrees of bronchoconstriction, reducing expiratory flow and ventilatory efficiency effects described mechanistically by Davis et al., 2008 in their analysis of β-adrenergic physiology. Even β_1-selective agents may indirectly limit ventilation by reducing cardiac output and thereby constraining oxygen delivery. These alterations become more pronounced during high-intensity effort, when ventilatory capacity is already challenged.

Metabolic consequences further contribute to the decline in endurance performance. In their controlled human studies Cléroux et al., 1989 reported that beta-blockers reduce catecholamine-stimulated lipolysis, limiting the mobilization of free fatty acids and increasing reliance on glycogen stores. As a result, athletes under beta-blockade tend to experience earlier glycogen depletion and reduce tolerance of prolonged exercise. Tesch, 1985 highlighted additional thermoregulatory challenges, noting that beta-blockade reduces heat dissipation and may compromise performance in warm conditions. These metabolic and thermoregulatory constraints are particularly detrimental in long-duration events where energy efficiency and heat management are essential.

The influence of beta-blockers on neuromuscular control has been one of the most significant factors shaping their role in sport-specific performance. The study by Kruse et al., 1986 provided evidence that propranolol improves pistol shooting accuracy by reducing physiological tremor and stabilizing motor output. Their findings remain one of the foundational demonstrations that beta-blockers can enhance performance in tasks requiring fine motor precision. Davis et al., 2008 explained the mechanistic basis for this effect, noting that β_2 receptor activity contributes to oscillatory behaviour in skeletal muscle, which increases under sympathetic activation. By antagonizing these receptors, propranolol suppresses tremor amplitude and provides a steadier neuromuscular platform for aim-dependent tasks.

Psychophysiological effects add an additional layer to the performance profile of beta-blockers. Brantigan et al., 1982 demonstrated that propranolol effectively reduces stage fright by diminishing somatic symptoms of anxiety such as palpitations, sweating, and tremor. Their work, although not conducted in athletes, directly parallels the conditions encountered in high-pressure sport settings, particularly in events where stress-induced physiological arousal can disrupt performance. Davis et al., 2008 similarly underscored the role of β-adrenergic activation in stress responses, reinforcing why suppression of sympathetic symptoms may be beneficial in specific athletic contexts.

More recent data have added nuance to this understanding. In a crossover trial, Ergen et al., 2021 evaluated the effects of beta-blockers on archery performance and found that although beta-blockade reliably reduced heart rate, it did not consistently improve shot accuracy or postural stability. These findings suggest that the performance-enhancing effects observed in early shooting studies are not universally replicable and may depend on athlete experience, baseline tremor characteristics, or the specific demands of the task. This modern evidence indicates that the relationship between physiological suppression and performance in precision sports is more complex than simple tremor reduction.

4. Anti-Doping Regulations and the World Anti-Doping Agency Framework

The regulation of beta-blockers in competitive sport is shaped by their unique physiological and sport-specific effects, which differ fundamentally from those of more universally ergogenic substances such as anabolic steroids or stimulants (García-Arnés et al., 2022; Wenbo & Yan, 2023; Docherty, 2008). Rather than imposing a blanket prohibition across all disciplines, the World Anti-Doping Agency (WADA) has adopted a targeted approach based on the principle that a substance should be banned only when it has the potential to enhance performance, pose a health risk, or violate the spirit of sport in a particular competitive context. The role of beta-blockers is therefore situated at the intersection of pharmacological evidence, ethical considerations, and sport-specific competitive fairness.

Beta-blockers are included in the WADA Prohibited List not as universally banned substances, but as drugs prohibited in competition within selected sports in which their unique effects: particularly tremor suppression, heart rate reduction, and attenuation of performance anxiety can provide a clear advantage. The 2025 WADA Prohibited List identifies precision sports such as shooting, archery, billiards, darts, certain ski disciplines, and specific motor sports as disciplines in which beta-blockers are prohibited because performance

depends heavily on motor steadiness and psychophysiological control (World Anti-Doping Agency, 2024). This regulatory stance is rooted in decades of empirical evidence beginning with early controlled experiments such as those by Kruse et al., 1986, who demonstrated that propranolol improved pistol shooting accuracy through reductions in tremor and enhanced aiming stability. These findings implies that beta-blockers could meaningfully alter competitive outcomes in sports where minute neuromuscular variations determine success.

Complementary evidence from psychophysiological research, including the work of Brantigan et al., 1982 on stage fright, supports WADA's view that beta-blockers may also enhance performance by dampening somatic anxiety in high-pressure environments. This is particularly relevant in finals or elimination rounds, where athletes must execute fine motor tasks under intense psychological stress. Davis et al., 2008 further elaborated on the adrenergic mechanisms responsible for such effects, highlighting the link between β-adrenergic activity and stress-related performance fluctuations. Together, these studies contribute to the scientific foundation on which WADA's selective prohibition is based.

The regulatory framework also incorporates mechanisms for allowing athletes with legitimate medical needs to continue participation through the Therapeutic Use Exemption (TUE) process (World Anti-Doping Agency, 2018). Conditions such as hypertension, arrhythmias, angina, or severe anxiety disorders may require treatment with beta-blockers, and the TUE system provides a pathway for medically justified use while maintaining fairness in sport (Archer et al., 2025; Hartono et al., 2024; Grandi & Ripplinger, 2019).

However, because beta-blockers may provide a competitive advantage in certain disciplines, TUEs for these substances undergo particularly rigorous scrutiny. The principle guiding TUE assessment requires that the athlete would experience significant health impairment without treatment, that no reasonable alternative exists, and that the therapeutic use does not enhance performance beyond the athlete's normal physiological capacity (World Anti-Doping Agency, 2018; Conviser et al., 2017). In precision sports, these criteria are difficult to satisfy because the therapeutic effects of beta-blockers may overlap substantially with potential performance-enhancing effects.

The regulatory debate surrounding beta-blockers has also prompted discussion within the sports community regarding the broader ethics of performance enhancement. Unlike substances that directly increase power, strength, or endurance (Wenbo & Yan, 2023; Docherty, 2008; Avois et al., 2006), beta-blockers exert their potential benefits through the reduction of physiological noise and emotional arousal. Some commentators have argued that these effects resemble non-pharmacological strategies such as breathing exercises or psychological skills training. However, the empirical evidence from Kruse et al., 1986, Brantigan et al., 1982, and Davis et al., 2008 demonstrates that beta-blockers operate through specific neurochemical pathways that suppress adrenergic drive more effectively than behavioural methods alone. This distinction reinforces WADA's position that pharmacological suppression of tremor and anxiety constitutes an artificial enhancement of fine motor performance, and therefore falls within the remit of anti-doping regulation.

In recent years, debates have emerged regarding whether the scope of beta-blocker prohibition should expand or contract. Contemporary findings, such as the mixed results reported by Ergen et al., 2021 in archery, suggest that the performance-enhancing effects are not universal and may depend on individual athlete characteristics. However, WADA's regulatory framework emphasizes the potential for competitive advantage rather than a requirement for consistent enhancement across all individuals (World Anti-Doping Agency, 2024). Because even small performance differentials can determine medal outcomes in precision sports, the possibility of benefit for some athletes is considered sufficient grounds for maintaining prohibition.

5.Discussion and Conclusions

Beta-blockers occupy a distinctive position within sports medicine and anti-doping science due to their highly specific physiological and performance-related effects. Their ability to suppress sympathetic activation, lower heart rate, reduce tremor, and diminish somatic manifestations of anxiety has profound implications for competitive environments in which stability, precision, and emotional control are essential components of performance. At the same time, the cardiovascular, respiratory, and metabolic constraints imposed by beta-blockade clearly impair endurance capacity and limit performance in sports that depend on maximal aerobic output or rapid neuromuscular activation. This contrasting profile highlights that the impact of beta-blockers is not uniform across athletic disciplines but is instead deeply dependent on the physiological demands of each sport.

The evidence available to date demonstrates that beta-blockers may provide meaningful advantages in precision-based disciplines, while acting unequivocally as performance-reducing agents in endurance or high-intensity events. This sport-specific pattern forms the rationale behind their selective regulation within modern

anti-doping frameworks. Such an approach aims to preserve competitive fairness while ensuring that athletes with legitimate medical needs may continue participation under carefully controlled therapeutic exemptions. As scientific understanding of individual variability and psychophysiological factors continues to evolve, ongoing evaluation of beta-blocker regulation will remain essential to maintaining integrity and equity in competitive sport.

Funding Statement: The article did not receive any funding.
Conflict of Interest Statement: No conflicts of interest to declare.

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