ISSN: 2641-0451

Review Article

Toxicology and Applied Pharmacology Insights

The Most Well-Known Ergogenic Aids are Pharmacological Substances

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Submitted: 2026, Apr 07; **Accepted:** 2026, May 12; **Published:** 2026, May 21

Citation: Franjic, S. (2026). The Most Well-Known Ergogenic Aids are Pharmacological Substances. *Toxi App Phar Insig, 8*(1), 01-05.

Abstract

Ergogenic aids encompass a broad range of substances aimed at enhancing performance, typically in the realm of sports. This term can describe natural compounds that boost stamina, as well as advanced materials believed to enhance speed, like certain biomaterials that assist runners in increasing their pace. Moreover, ergogenic aids can also involve psychological techniques, including pre-event calming methods or visualization that can lead to improved performance. Additionally, it can pertain to a specific approach to training.

Keywords: Ergogenic Aids, Athlete, Blood, ANS, Doping

1. Introduction

Two fundamental elements crucial for achieving success in sports are genetic predisposition and training status [1]. At specific competitive levels, athletes usually possess comparable genetic capabilities and have undergone similar training approaches, making them relatively equal in performance. With the drive to succeed, many athletes preparing for contests are continually on the lookout for the ultimate technique or component that can give them a competitive advantage. In fact, there are claims that two significant contributors to enhanced athletic performance in recent times are dietary improvements and ergogenic aids.

The term ergogenic originates from Greek roots, with "ergo" meaning work and "gen" signifying production, and it is typically understood as a way to boost work capacity [2]. In athletics, a variety of ergogenic aids have been utilized for their potential to enhance athletic performance by improving physical strength, mental resilience, or mechanical advantages. These aids are categorized differently based on how they relate to sports.

Ergogenic literally refers to augmenting the body's energy for both physical and psychological tasks. For athletes, coaches, or professionals in athletic care, an ergogenic aid is typically seen as a method or substance that enhances performance beyond what is typically achieved through effective training practices and proper nutrition. While some discussion exists about potential ergogenic aids for bone and connective tissues, the available research on this topic is significantly less advanced concerning exercise and healthy athletes. The effectiveness of each ergogenic aid is assessed based on (1) its mechanism of action, (2) supporting research, (3) practical usage, and (4) risk of negative side effects.

1.1. ATP

The main energy source for muscle movement is adenosine triphosphate (ATP) [2]. Since the stored ATP in muscles is insufficient for extended contractions, it has to be continuously resynthesized. The breakdown of glucose through the glycolytic pathway and the release of reducing equivalents via the citric acid cycle supply the electron transport chain in muscle mitochondria, which consumes oxygen and produces ATP. Glucose for this process can be derived either from the breakdown of muscle glycogen (glycogenolysis) or from the absorption of blood glucose, which remains relatively stable for a while because the liver's glucose production matches the muscle's glucose use. Similarly, fatty acids released from peripheral fat tissues or from intramuscular triglycerides can serve as substrates for the citric acid cycle, leading to ATP production via the electron transport chain. This process of fatty acid oxidation is crucial, particularly during endurance activities, as it reduces the reliance on the limited glucose supply for creating ATP. Finally, amino acids produced from protein breakdown can serve as carbon skeletons for intermediates in the citric acid cycle, thus aiding in the generation of reducing equivalents during physical activity. Additionally, amino acids such as alanine and glutamine act as gluconeogenic precursors in the liver, supporting the liver's glucose production.

1.2. hGH

Endogenous human growth hormone (hGH) is released by the pituitary gland and plays a significant role in managing various metabolic and growth functions within the body [3]. In medical settings, hGH, also referred to as somatotropin, is utilized to address growth issues in children; however, it has recently attracted interest due to claims of its potential to slow down aging and enhance strength. Studies have indicated that while hGH does promote muscle size, it does not correlate with strength gains. Numerous athletes and bodybuilders use hGH for its purported benefits such as fat reduction, enhanced lean muscle mass, increased energy levels, and improved immune response. These changes in body composition are partly attributed to hGH's ability to preferentially utilize fats as energy rather than carbohydrates.

As a performance-enhancing agent, hGH is recognized for its anabolic effects, contributing to muscle growth through enhanced amino acid uptake and protein synthesis. Although hGH is not classified as a controlled substance, its use for performance enhancement is prohibited. The hormone is typically delivered through intramuscular or subcutaneous injections. Unfortunately, hGH can also cause excessive growth in bone and cartilage, particularly evident in the jaw and forehead (acromegaly). Other potential side effects associated with hGH use include fluid retention, carpal tunnel syndrome, insulin resistance and heightened diabetes risk, increased chances of osteoporosis, sexual dysfunction, liver and spleen enlargement, and potential heart damage. The National Collegiate Athletic Association (NCAA), as well as the International Olympic Committee and the World Anti-Doping Agency (WADA), have banned the use of hGH.

1.3. Blood

The cardiovascular system plays a crucial role in how the body responds to endurance activities [2]. The heart rate, volume of blood ejected, and blood pressure rise to ensure that blood is effectively circulated throughout the network of blood vessels. Mechanisms such as vasodilation and vasoconstriction direct blood flow appropriately, ensuring that active skeletal muscles receive sufficient blood supply while organs with lower metabolic rates, like the intestines, spleen, and kidneys, receive less. Sufficient blood flow to skeletal muscles during contraction is vital to satisfy the greater demands for oxygen and nutrients, including glucose, fatty acids, and amino acids, as well as to eliminate metabolic byproducts such as carbon dioxide, lactate, and amino nitrogen produced during amino acid transamination and deamination. The metabolic functions in skeletal muscles are not entirely efficient, resulting in heat production that must also be expelled to maintain optimal temperatures in the muscles. The reduction of metabolic heat is predominantly managed through vascular modifications that redirect some blood flow to the skin. The dilation of blood vessels in the skin facilitates heat loss via conduction and convection. Nevertheless, the majority of heat loss occurs through evaporation. Sweat glands activated by heat release significant amounts of water and salts in the form of sweat. When this sweat evaporates from the skin, a cooling effect is generated. The cooling of the skin lowers the temperature of the blood that is directed to it, which helps prevent an excessive increase in core body temperature. Despite its effectiveness in cooling, the evaporation of sweat over extended periods can considerably deplete the body's water and electrolyte levels, leading to hypohydration. This can adversely affect cardiovascular functioning and hinder further heat loss.

1.4. Skeletal Muscle

Adaptations in cardiovascular and metabolic processes within skeletal muscle occur due to long-term endurance training [2]. These changes facilitate an increment in peak aerobic capacity, known as maximum oxygen consumption or VO2 max, while also significantly enhancing an athlete's capacity to sustain a higher level of aerobic performance in prolonged activities. This results in a quicker pace and subsequently shortens the time needed to complete a competitive distance.

Left ventricular hypertrophy is a major factor contributing to the enlargement of the heart that is associated with endurance training. This hypertrophy results in increased stroke volume and improved maximal cardiac output among trained individuals. During exercise, the submaximal heart rate decreases, which is attributed to a larger stroke volume and increased plasma volume that enhances venous return in those who are trained. Coupled with higher hemoglobin levels and improved capillary density in skeletal muscles, these cardiovascular enhancements enable more efficient oxygen delivery to the skeletal muscles during maximum exertion.

Regular endurance training triggers adaptations in skeletal muscle. The most significant change is the boost in mitochondrial biogenesis, resulting in an increased number of mitochondria and a larger mitochondrial network within the muscle cell structure. This enhancement facilitates more effective oxygen utilization during low-intensity workouts and enables the muscles to utilize a greater amount of oxygen supplied during high-intensity efforts. Furthermore, the functionality of individual mitochondria improves in trained individuals, demonstrated by rises in crucial enzymes that are integral to the Krebs cycle and electron transport activities, such as citrate synthase and cytochrome C oxidase. In trained skeletal muscle, there is a heightened ability to oxidize fatty acids for energy, which aids in preserving carbohydrates during extended physical activity. Interestingly, endurance training also leads to a rise in intramuscular triglyceride reserves. Additionally, the amount of muscle glycogen is likely increased due to enhanced insulin sensitivity. The production of lactate during low-intensity exercise is reduced in muscles that have undergone endurance training, alongside an improved capacity for lactate clearance and oxidation. This is reflected in lower blood lactate levels at any specific intensity of submaximal exercise in trained individuals. Finally, endurance training increases the activity of crucial internal antioxidant enzymes and systems, likely to manage the heightened production of reactive oxygen species, such as free radicals.

1.5. ANS

The actions involved in endurance exercise are initiated and controlled by neural pathways that connect within the central nervous system [2]. The central command theory posits that signals from brain nuclei located in the motor cortex activate motor nerves, leading to muscle contractions. Notably, signals from central command also engage brain regions that manage autonomic nervous system functions. Consequently, when there is a desire to exercise, the central command sends signals that stimulate spinal motor units as well as responses from the autonomic nervous system, preparing physiological systems to meet the demands of exercise. Peripheral feedback mechanisms and reflex actions play a vital role in this system because they help refine the signals from central command and autonomic nervous system outputs, ensuring that the motor activation level and overall physiological stability are suitable for the specific intensity of exercise.

ANS outflow holds significant importance for cardiovascular, temperature regulation, and metabolic adaptations required to maintain physical activity. The ANS affects these bodily functions in two main manners: (1) through the functioning of autonomic nerves and their release of chemical messengers, and (2) by how peripheral tissues react to the neurohormonal substances released into the bloodstream. For instance, the reduction of vagal nerve activity at the beginning of exercise leads to an increase in heart rate and cardiac output. As the intensity of exercise rises, further escalations in heart rate and ventricular contraction are achieved through the activation of sympathetic nerves in cardiac tissue alongside beta-adrenergic stimulation triggered by epinephrine released from the adrenal medulla. The increase in cardiac output during physical activity facilitates blood circulation to the muscles and helps maintain blood pressure despite significant vasodilation occurring within the muscles, which poses a risk of overall blood pressure decline and diminished perfusion capability. Fortunately, activation of the sympathoadrenal system also causes constriction of blood vessels, guiding blood flow away from tissues that are less metabolically active and directing more to the active muscles for oxygen and nutrient delivery, as well as to the skin for heat dissipation. Changes in metabolism resulting from sympathoadrenal activity involve elevations in lipolysis in peripheral fat tissue and glycogen breakdown in the liver induced by epinephrine. Increased levels of epinephrine also lead to decreased insulin secretion, facilitating enhanced lipolysis activation and glucagon release, which supports higher rates of liver glycogenolysis. Clearly, the central nervous system and autonomic nervous system play crucial roles in the physiological processes and adjustments necessary for transitioning from a state of rest to exercise.

1.6. Metabolic Responses

Typically, most endurance athletes do not conduct objective evaluations of their power or work output during events or training activities, although the rise of cycling computer systems and power cranks is making this more prevalent among cyclists [2]. Accordingly, during extended physical exertion, modifications in effort to accelerate, decelerate, or entirely halt are generally guided by subjective feelings. Interestingly, this fundamental and recognizable aspect of exercise remains the least comprehended. It remains unclear whether these subjective sensations stem from the central nervous system, arise as a consequence of peripheral feedback, or result from a combination of both expressed through complex neurological feedforward and feedback mechanisms. Nevertheless, it is established that the perception of physical effort correlates well with actual exercise intensity. A variety of psychological elements such as mood, determination, motivation, and arousal certainly influence the subjective experience of effort. Therefore, the feelings an athlete experiences, their past encounters, and their expectations are all essential components of the response to exercise.

The brain is certainly an organ that requires a significant amount of energy, and its metabolic processes respond to increased neural engagement, which in turn promotes that engagement. For instance, when the brain becomes active due to a cognitive task, there is an increase in overall blood circulation to the brain to provide essential oxygen and nutrients. However, during physical activity, the total blood flow to the brain resembles that at rest because it appears to be primarily regulated by levels of arterial carbon dioxide rather than by changes in the metabolic conditions associated with physical movement. As exercise intensity ramps up, the levels of arterial carbon dioxide decrease due to rapid breathing, resulting in the narrowing of small blood vessels in the brain and a reduction in blood flow, despite high brain metabolic activity. Thankfully, increased extraction of oxygen can balance the reduced blood flow in these situations. The regional circulation within the brain might play a more crucial role at the beginning and during ongoing exercise. While exercising, blood supply to the motor regions of the brain rises, as does the flow to the areas responsible for sensorimotor functions, likely for the purpose of adjusting central commands or receiving feedback related to fatigue. Moreover, physical activity boosts blood flow to brain regions that manage cardiovascular, breathing, and temperature regulation.

The increase in localized blood circulation within the brain is essential not only for delivering oxygen but also for providing glucose. Glucose serves as the primary energy fuel for brain cells, and a constant systemic supply is crucial since neuronal tissues have very limited glycogen reserves. During rigorous exercise, the metabolism of glucose in the brain can hinder performance in two significant ways. First, if the activity of neurons exceeds the ability for aerobic and anaerobic glucose metabolism, the functioning of brain cells will decline, compromising the effectiveness of central commands and the regulation of homeostasis. Secondly, the energy produced from oxidizing glucose in brain cells will be converted entirely into heat because these cells do not perform mechanical work. Although this heat is typically dissipated adequately through cerebral circulation under normal conditions, during exercise—especially in hot environments—removal of heat from the brain becomes less effective, leading to potential heat accumulation.

1.7. Doping

Sports medicine professionals face numerous ethical dilemmas related to doping control [4]. Physicians may engage in a range of relationships with athletes, including traditional doctor-patient dynamics, which can affect the use and potential misuse of performance-enhancing substances. In the standard doctor-patient relationship, it is the physician's duty to avoid causing harm while also striving to enhance the health of the patient. This often results in a mix-up between the therapeutic and performance-enhancing applications of medications.

A doctor can find themselves in challenging situations where they must juggle conflicting priorities, such as an injured sports player who could gain from using a banned substance. Another situation involves a patient seeking prescribed medications to sidestep potential hazards linked to illegal suppliers. Athletes often engage in the practice of visiting multiple doctors until they discover one willing to meet their demands, and the doctor must consider the financial loss from the patient against their ethical obligations.

The physician–patient dynamic is further complicated when the physician has a relationship to a sports organization. Being a team physician for a high-profile sports team often has significant benefits to the physician in terms of prestige, finances, and community visibility. The position of team physician can be so desirous that a number of US professional teams have entered into "medical sponsorship" arrangements in which the role of team physician goes to the highest bidder (i.e., the physician compensates the team). The status that accrues to the physician and the desire to maintain that status creates the potential for conflict. A physician may be pressured by the athlete or employing organization to prescribe ergogenic drugs unethically. As the athlete is not paying the physician, this often confuses the traditional doctor–patient relationship.

These three concerns – the wish to assist in recovery, changed dynamics in the doctor-patient relationship, and the status of team physicians – can lead to the unethical prescribing of performance-enhancing substances by doctors. Because of the strict regulation surrounding substances like anabolic steroids, there exists the temptation for a physician to provide these drugs to athlete-patients for reasons beyond medical necessity or for financial profit. Notably, the misuse of medical professionals is exemplified in the context of the records from the GDR when doctors actively participated in the government-sponsored doping initiative.

On a brighter note, medical practitioners are integral to anti-doping initiatives across nearly all national and international sports organizations. Frequently, they hold significant roles in these endeavors. In the United States, medical professional involvement is mandatory for every review board considering doping violations. Furthermore, physicians often play a key part in treating athletes who become reliant on performance-enhancing substances.

1.8. Alcohol

For athletes, engaging in sports introduces a distinctive kind of stress that occurs not only prior to key events but also from regular participation in competitions [5]. Although a degree of anxiety before competing is natural, individuals respond to this stress in vastly different ways, with some struggling significantly. Many athletes resort to personal methods to manage their anxiety, opting for internal strategies instead of external aids. Anxiety can negatively impact performance, particularly in tasks requiring significant mental focus and physical steadiness. This potential decrease in performance has led to the adoption of anti-anxiety medications.

The mental response to the pressure of upcoming sports competitions is commonly referred to as anxiety, arousal, stress, or activation. Anxiety denotes feelings of worry or emotional strain, arousal describes a spectrum from sleepiness to heightened excitement, stress points to factors that create pressure within the body, and activation highlights the physiological state in reaction to stressors. A moderate amount of anxiety regarding the upcoming challenge is beneficial for generating the right amount of motivation to take action. The simpler the task at hand, the greater the anxiety that can be endured before performance begins to decline.

Excessive anxiety negatively impacts both the physical and mental coordination required for optimal sports performance. When this occurs, strategies aimed at reducing anxiety can provide an ergogenic advantage. Athletes or their coaches might need to decide between employing relaxation techniques or using pharmaceuticals to ease anxiety. While alcohol may be utilized to mitigate stress in those feeling overly anxious, any benefits gained must be weighed against potential adverse impacts on physical capabilities and neural control.

The degree of anxiety experienced can greatly vary based on both the specific sport and the individual athlete. Elevated anxiety levels are often tied to short-duration, high-risk activities. Observable anxiety responses prior to a competition are evident through phenomena like emotional tachycardia, with motor racing, ski jumping, and downhill skiing ranking at the forefront.

In precision sports, such as archery, maintaining a stable limb is essential for providing a solid base for accurately aiming at the target or for keeping the weapon steady.

The aftereffects of alcohol can persist into the next day, influencing workouts or performance in upcoming competitions. Additionally, there is a potential for building tolerance to the substance with long-term use or for developing a dependence on the drug.

2. Conclusion

Endurance sports place significant stress on the athlete's entire system, from the lungs to the bloodstream to the muscles. To maintain endurance, the athlete's muscles require a constant supply of oxygen contained in red blood cells. Results are sought, but one should not overdo it.

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