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Evaluating the Effects of Energy Drinks on Athletic Performance and Health

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Abstract

Energy drinks (EDs) have gained popularity in recent years due to claims by ED companies that these beverages acutely enhance physical and intellectual performance. With caffeine being the primary active ingredient, its stimulating properties are thought to be responsible for the reduction of fatigue, increased alertness, and increased sympathetic activity which consequently drives improvements in performance. Although this review finds support for these attractive benefits, it also reveals that EDs have been associated with significant adverse effects such as cardiac arrhythmias, psychotic events, and acute kidney injury among others. This review also finds associations between ED consumption and destructive behaviors in adolescents. This is of particular concern as adolescents have become the largest consumers of EDs. Through an analysis of the marketing techniques employed by ED companies, this review suggests that the disproportionate consumption by adolescents can be attributed to targeted marketing strategies that leverage the sporting interests of this demographic. This review largely summarizes the acute effects of ED consumption on health, though research on chronic health effects is limited. Therefore, additional research on the chronic health effects of EDs is called for, particularly on adolescents.

Background

An energy drink (ED) is a beverage designed to improve mental acuity and/or athletic performance through various stimulants. Oftentimes, these beverages contain large amounts of sugar and caffeine, but may also contain varying quantities of taurine, B-vitamins, and other ingredients.

Of these ingredients, the stimulating effects of EDs can be mostly attributed to caffeine–a natural stimulant and socially acceptable drug. It is commonly found in beverages such as coffee, tea, soda, and EDs, but in recent years, has also become available in the form of energy bars, gels, and chewing gum.[1] Although caffeine is regarded as “safe” for adults when ingested in low to moderate quantities, the acute ingestion of large quantities of caffeine has been associated with negative health

outcomes–particularly cardiological and neurological pathologies. For children, consumption of caffeinated EDs is not recommended but there are currently no regulations that restrict their sale.[2]

Nevertheless, consumption of highly caffeinated EDs has become prominent among individuals seeking the performance benefits to which ED companies claim. This increasing market for EDs has led to the development of research to validate these claims and to further investigate the effects of EDs on health.

Athletic Performance

Several studies have demonstrated a positive correlation between ED consumption and benefits to athletic performance. Moreover, these beneficial effects apply to a variety of sporting events including soccer, volleyball, and cycling, among others. Improvements to athletic capabilities have been associated with two stimulants that are common ingredients in most EDs: caffeine and taurine.[3,4,5]

Of the two ingredients, the ergogenic effects of caffeine are the most understood. Primarily, caffeine functions as a stimulant of the central nervous system by blocking peripheral and cerebral adenosine receptors, resulting in delayed onset of fatigue.[6] Caffeine also increases motor neuron recruitment and is associated with an increase in the release of Ca2+ from intracellular neuronal reserves.[7] Aside from neuronal stimulation, it also plays an important role in exercise metabolism; caffeine increases the mobilization of glycerol and free fatty acids in the bloodstream, allowing for increased efficiency of beta-oxidation during low to moderate intensity exercise.[8] Lastly, caffeine also stimulates the secretion of epinephrine which systematically enhances sympathetic activity. These combined mechanisms result in increased energy production that is responsible for improvements in athletic performance.[8]

The dosage of caffeine intake that yields performance benefits has also been researched. In a 2019 randomized controlled trial by Polito *et al.*, the effects of two different caffeine concentrations (3 and 6 mg/kg body weight) were compared against a placebo when assessing resistance training performance. The results indicated that caffeine supplementation (3 or 6 mg/kg) significantly improved performance when

compared to the placebo, though no statistical difference was observed between the two caffeine concentrations.[9] Furthermore, some studies provide strong evidence that acute consumption of at least 3 mg/kg of caffeine is necessary to observe performance improvements.[3] Although there are genetic variances that influence the effectiveness of caffeine,[10] the literature suggests that the optimal dose for ergogenic effects lies between 3–6 mg/kg body weight.[3,7] In addition, increasing the dose of caffeine beyond this range poses a significant risk of side-effects and is not necessary to elicit improvements in athletic performance.[11]

As for the effects of taurine on sports performance, the proposed mechanism of action involves the stimulation of Ca2+ release from the sarcoplasmic reticulum, maintaining sensitivity to muscle contraction by directly acting upon excitation-contraction coupling.[12] In recent studies, improvements in VO2max, time to exhaustion, time-trial performance, anaerobic performance, and peak power have been reported.[13,14] However, the effects of taurine remain controversial as many studies have also reported no effect in the very same performance parameters.[15,16] Evidence for taurine dose recommendations is also conflicting. For example, some studies show performance benefits at 1g and others find no effect with the same dose.[16,17] Therefore, given the variance in the current literature, the effects of taurine on athletic performance remain unclear.

Effects of Energy Drinks on Health

Over the past two decades, significant adverse effects have been attributed to excessive ED consumption–most notably, adverse effects on the cardiovascular and neurological systems which are thought to be caused by the neurostimulant ingredients of these beverages.[18,19] However, significant adverse effects have also been reported across the major organ systems. These range from mild adversities such as anxiety, headaches, insomnia, gastrointestinal disturbances, dehydration, nervousness, and tachycardia, to severe outcomes such as acute kidney injury, rhabdomyolysis, ventricular fibrillation, seizures, acute mania, stroke, and death.[18,20,21] In large part, these adverse events are associated with caffeine intake that is greater than 400 mg/day for adults. The FDA's

aforementioned “safety limit” encompasses all caffeine sources and is not exclusive to EDs.[22]

This review summarizes the adverse effects of EDs on the cardiovascular system, nervous system, and renal system, from 10 case report articles within the last 20 years. Of the 10 case report articles, 5 reported cardiovascular adverse events, 3 reported neurological adverse events, and 2 reported renal adverse events. A total of 50 cases were reviewed and organized on the basis of the reported adverse events within each organ system.

For the cardiovascular system, the most prevalent adverse effects were arrhythmias (33%), cardiac arrests (14%), dissections (14%), and heart attacks (12%) (*Figure 1)*.[18,23,24,25,26] For the neurological system, the most prevalent adverse effects were clonic seizures (38%) and psychiatric disorders (38%), the latter of which is specified to include hallucinations, delusions, and disorganized thoughts (*Figure 2)*.[27,28,29] For the renal system, the most prevalent adverse effects were acute kidney injuries (50%), followed by rhabdomyolysis (17%), and hyponatremia (13%) (*Figure 3*).[30,31]

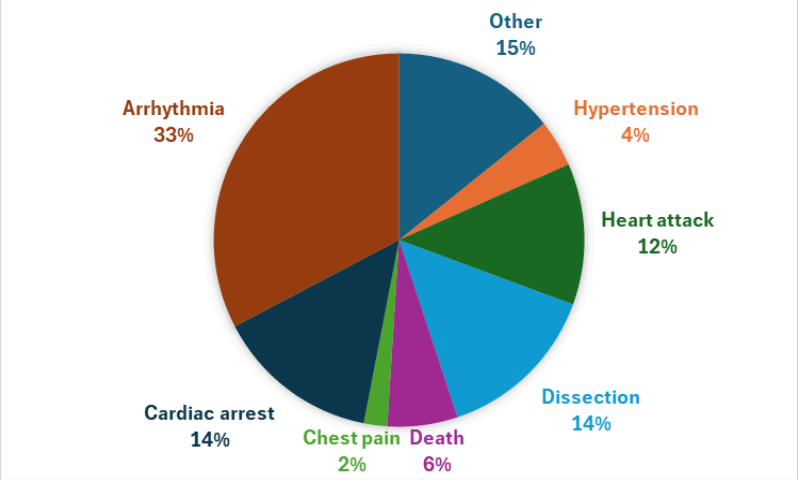


Figure 1. Cardiovascular adverse effects associated with energy drink consumption (n=30).

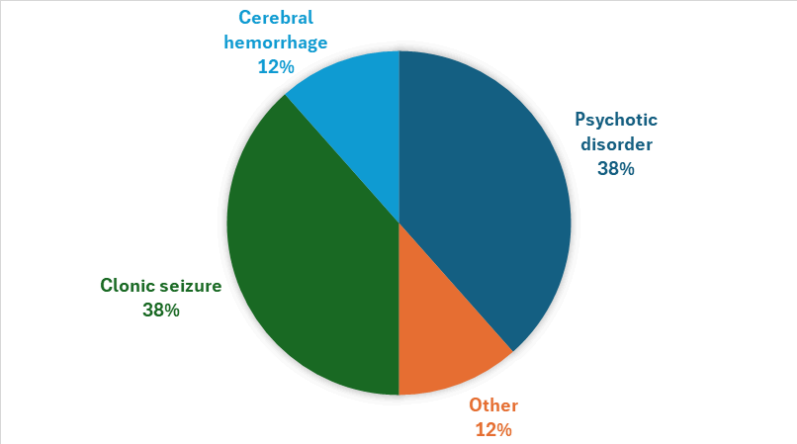


Figure 2. Neurological adverse effects associated with energy drink consumption (n=14).

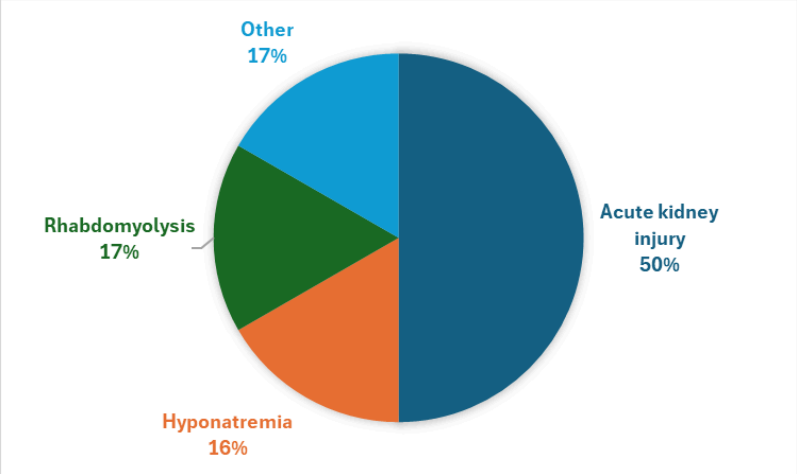


Figure 3. Renal adverse effects associated with energy drink consumption (n=6).

Targeted Marketing Practices Towards Adolescents

Despite the well-studied prevalence of adverse events associated with EDs, ED companies continue to market their performance benefits which have been validated by the current literature.[32] Many claim that their beverages increase alertness, reduce fatigue, improve athletic performance, and promote recovery. In doing so, their popularity has risen exponentially, amounting to a multi-billion dollar industry since their appearance in 1987.[1] What is especially concerning is that adolescents make up the highest proportion of ED consumption (68%) , followed by adults, then children.[33] Consequently, minors in particular face the highest risk of developing ED-associated adverse events.

An explanation for this disproportionate consumption by adolescents is described in a 2022 research paper by Bleakley *et. al.*. After analyzing 315 popular ED advertisements from social media and television platforms over a 4-year period, it was found that extreme sports themes, endorsements by professional athletes, and the promise of improved athletic performance, creates a targeted appeal to adolescents.[34] This finding can be confirmed by research that studied the perceptions of these advertisements by adolescents. In a randomized controlled trial, 2,044 Canadians between the ages of 12 and 24 were randomly assigned to view an ED ad that was either sports themed or non-sports themed (control). Afterwards, their perceptions of the ad were assessed through a survey. The main finding was that 70.1% of respondents who viewed the sports-themed ad thought that it targeted people their age or younger.[35] Interestingly, ED companies have gone beyond simply crafting sports-themed ads; they have been committed to actively increasing adolescent exposure to their beverages. One study analyzed the proportion of ED advertisement airtime among popular television channels. This study found that the channels with the largest ED advertisement airtime were those whose base audience were between the ages 12 and 17.[36]

As EDs continue to gain popularity due to these targeted marketing strategies, investigation of their specific effects on adolescents has driven research in the past two decades.

Effects of Energy Drinks on Adolescent Health

Although there is limited research on the effects of ED consumption on adolescent health, negative neurological and behavioral outcomes in adolescents are the most supported. For example, analysis of a survey given to a representative sample of 10,406 Finnish adolescents aged 12–18 years old found a strong correlation between daily ED consumption and headaches, fatigue, and insomnia.[37] Furthermore, a study that administered health behavior surveys to 1,649 middle school students found that students who reported ED consumption were 66% more likely to be at risk for hyperactivity/inattention.[38]

Additional studies assessing the correlation between EDs and behavioral changes among adolescents have also populated the literature in the past few years–many of which suggest a strong correlation between EDs and destructive behaviors. These behaviors include aggressiveness, sensation-seeking, binge-drinking, problematic social media use, lack of sleep, skipping breakfast, and inadequate tooth brushing. ED consumption was also found to correlate strongly with tobacco and soft drug use.[39,40]

The effects of EDs on the cardiovascular health of adolescents has also been a focus of interest in the past 2 years–particularly by the Department of Pediatric Cardiology and Pediatric Intensive Care in the Hospital of the University of Munich. In 2022 and 2023 this department published several papers assessing various cardiovascular parameters in response to ED consumption. One of these studies is a randomized, single-blind, placebo-controlled study that investigated the acute effects of EDs on arterial stiffness in 27 healthy children and adolescents. The ED that was given to the treatment group was weight-adjusted to 3 mg/kg of caffeine while the placebo maintained the same sugar content and did not contain other ED ingredients. The result of this study was that ED intake significantly decreased peak circumferential strain of the common carotid artery ($11.78 \pm 2.70\%$ vs. $12.29 \pm 2.68\%$, $p = 0.043$) compared with the placebo, indicating an acute increase in arterial stiffness.[41]

In the broader context, increased arterial stiffness is correlated with increased risk of cardiovascular pathologies; namely, increased afterload, altered coronary perfusion, and left ventricular dysfunction.[42,43] Alarmingly, research has also suggested that

increased arterial stiffness in pediatric populations may lead to structural vascular changes early in life.[44]

In terms of adverse effects on other organ systems in adolescents, the current literature is limited. Yet, some research suggests that adolescent consumption of EDs may result in kidney injuries. Taurine may contribute to the ED-associated adverse effects on the kidneys, especially when alcohol is concurrently ingested–a practice that has become widespread among young people as mixtures of caffeine and taurine have been shown to negate the negative side-effects of alcohol.[45] However, because taurine plays a role in modifying renal blood flow and controlling osmolarity of the renal medulla, excessive taurine may contribute to renal pathophysiology by inducing tubular necrosis. This outcome was observed in a case report of a 17 year old boy who consumed multiple energy drinks (totalling 4600 mg of taurine) with 380ml of alcohol and suffered acute renal failure.[45]

Conclusion

Over the past few years, substantial evidence has surfaced suggesting improved performance benefits across multiple sporting disciplines as a result of ED consumption. Caffeine is thought to be the primary ingredient responsible for these benefits. While taurine from EDs has been shown to improve athletic performance in some studies, the current literature regarding its efficacy is limited and conflicting.

Additionally, evidence has surfaced that associates ED consumption with cardiovascular, neurological, gastrointestinal, and renal illnesses. However, the additional risk of destructive behavioral changes has also been widely reported in adolescents.

Despite these negative findings, ED companies have continued to advertise the ergogenic benefits of EDs, but have targeted their marketing towards adolescents. By using sports themes, celebrity endorsements, and other marketing strategies, their specific appeal to adolescents has caused this population to comprise more than two-thirds of ED consumption, placing them at greater risk for ED-associated adverse effects. Therefore, as ED consumption among adolescents continues to rise, this review hopes to support legislative regulation on the sale of EDs to minors. Further research on the chronic health effects of energy drinks is also warranted from the scientific community.

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