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Original article

The Impact of Energy Drinks on Adolescents' Health: A Review

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Abstract
Energy Drinks (ED) are beverages formulated to improve alertness, concentration, and physical performance. Recently, they have been widely consumed by adolescents because of their perceived ability. Their presence in the market has grown exponentially, mainly in urban areas. However, growing evidence indicates that excessive consumption is associated with cardiovascular, psychological, gastrointestinal upset, neurological, metabolic, muscle twitching, restlessness, and periods of inexhaustibility. Recent studies have found that ED consumption is associated with increased blood pressure, platelet aggregation, and arrhythmias. Several case reports have described individuals who experienced ventricular fibrillation, myocardial infarction, and cardiac arrest shortly after consuming ED. The underlying mechanisms are not fully understood but may involve the effects of caffeine and other ingredients on the sympathetic and cardiovascular systems. This review revealed essential aspects to understand these growing dilemmas in urban countries around the world: The composition of ED, their physiological effects, health consequences, and public health implications.
Keywords: Energy Drinks, Co-Ingestion, Cardiovascular Diseases, Hepatorenal Injury.

Introduction

Energy Drinks are defined by the Food and Drug Administration (FDA) as a liquid form of a non-alcoholic beverage containing a large amount of caffeine, with or without other ingredients such as sugar, vitamins, amino acids, and herbal stimulants. Global consumption of these drinks has increased significantly among adolescents and young adults due to their effects on enhancing cognitive and physical performance [1]. Consumers derive energy from the carbohydrates in these beverages. The energy provided by caffeine and other potential stimulants is uncertain at best, despite what marketing campaigns might suggest. However, sugar-free versions of these drinks are available, and this term is used here for consistency. Brand names are usually used [2,3]. The first energy drink appeared in the U.S. in 1949 and was marketed as “Dr. Enuf”. In Europe, they were first introduced in 1987 and became very popular after Red Bull's launch in 1997. Their presence in the global market has grown exponentially, with various brands released mainly in urban areas. The annual consumption of ED in 2013 exceeded 5.8 billion liters in around 160 countries. The estimated total U.S. retail market value for ED was around 12.5 billion USD in 2012, and the market increased 56% from 2002 to 2006. In 2016, more than 20 energy drink brands were available for sale in the UK. It was recorded that 3.74 million people consumed the energy drink Red Bull in the UK that year, making it the most popular energy drink brand by consumption. Energy drink sales accounted for 13.4% of the soft drink market in the same year [4,5,6,7].

In 2017, the global market research firm Mintel released a report on sports drinks and ED. It is projected that energy drink sales volume increased by 19% since 2012, reaching 669 million liters in 2017, and that the market expanded to include various types of sweeteners. The company predicted an additional 10% growth in the size of the "ED" market during the period 2017-2022, reaching 739 million liters, and a 25% growth by 2022, exceeding the two-billion-pound mark [3].

Approximately two-thirds of energy drink consumers are 13–35 years old, and boys are two-thirds of the market. In the U.S., ED is the second-most-consumed dietary supplement by young people. In Libya, ED is widely consumed among people aged 8->50. According to El-Shintiri et al. 2022, the prevalence of energy drink consumption among college students at the Libyan International Medical University (LIMU) in Benghazi, Libya, was 59.4% the majority being males (52.5%) [6]. In Libya, popular international brands like Red Bull, Monster Energy, and Power Horse dominate the market. Local consumers also regularly purchase brands such as Kabisa and Shark. Prices in local shops and delivery services generally range from 5.000 to 15.000 LYD, depending on the brand and the can size. [7]

Top energy drinks available in Libya include Red Bull, which is the global staple usually found in 250 ml cans priced around 14.000 LYD. Monster Energy is popular for its larger 500 ml cans, costing about 15.000 LYD, with variants such as Mango Loco, Monarch, and Zero Sugar readily available. Kabisa is an internationally recognized brand highly popular in the Libyan market, known for its fruity taste. Power Horse and Shark are widely stocked beverage options, typically costing between 10.000 and 12.000 LYD [6,10].

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Table 1. Reasons for drinking the ED [12, 14]

Country	Physical performance (%)	Help with study (%)	Energy boost (%)	Taste (%)	Peer pressure/ Advertising/ Availability/ Price (%)	Other (%)	Reference
EU countries	7		38	40		15	Zucconi et al (2013)
Poland				47	33	22	Nowak & Jasionowski2016
SaudiArabia (Adolescents and adults)	25.6	14.6	20.8			39	Aluqmany etal(2013)
Saudi Arabia	13	3	44	33	3	4	Faris (2013)
Pakistan (adults)	10	15	25	9	11	22	Usman et al(2015)

Composition of ED

ED is designed to give consumers an energy boost through a combination of stimulants and energy enhancers. Common ingredients include caffeine, taurine, guarana, glucuronolactone, ginseng, ginkgo biloba, B vitamins, carnitine, and significant amounts of sugar. Caffeine content can range from 80 to 300 mg per serving, while guarana may contribute additional caffeine that is not always clearly reflected on product labels [5,10–15].

Energy Drinks' main ingredients

Caffeine

The primary stimulant. It is usually sourced naturally via guarana, green tea, or coffee bean extract. An 8-ounce serving typically contains 40-250 mg of caffeine, which is much higher than the standard coffee or soda. The primary active component, caffeine, is a central nervous system stimulant that temporarily reduces fatigue and increases alertness by antagonizing adenosine receptors in the brain [15]. In addition, Caffeine is rapidly and completely absorbed in the small intestine within 1 h and diffuses quickly into other tissues (15). Caffeine is soluble in water and lipids, easily passes the blood-brain barrier, and is found in all body fluids, including cerebrospinal fluid and saliva (15). The difference in caffeine absorption time is dependent on the physicochemical formulation properties of the drink dose**.**

Coffee has been reported to have a protective effect against type 2 diabetes [7], and a meta-analysis (Shi et al., 2016) showed that controlled consumption of caffeine (3–6 mg/kg body weight) reduces insulin sensitivity. The sharp decline in glucose tolerance induced by caffeine may be due to increased plasma adrenaline and beta-receptor activity, given that insulin signaling is unaffected (Thong and Graham, 2002). Experimental evidence suggests that chronic caffeine consumption may reverse age-related insulin resistance in skeletal muscle (Guarno et al., 2013). The effect of caffeine on glucose homeostasis still requires further investigation.

Table 2. Caffeine and Sugar Content of Selected ED and Coffee Beverages[4].

Beverage Product	Caffeine per Serving (mg)	Serving Size (ml)	Caffeine Concentration (mg/L)	Estimated Dose for Age 10 (mg/kg)	Estimated Dose for Age 16 (mg/kg)	Sugar per Serving (g)	Sugar Concentration (g/L)
NOS	160	473	338	5.16	2.81	54	114
Monster	160	475	338	5.16	2.81	50	100
Monster Absolute Zero	140	473	296	4.52	2.46	0	0
Red Bull Energy Drink	80	250	320	2.58	1.40	27.5	110
Red Bull Sugar-Free	80	250	320	2.58	1.40	0	0
Red Bull Total Zero	80	250	320	2.58	1.40	0	0
Rockstar	160	473	338	5.16	2.81	60	127
Rockstar Zero Carb	240	473	507	7.74	4.21	0	0
V	109	355	307	3.52	1.91	37.1	105
Wicked	155	473	310	5.00	2.72	63.2	126
Relentless	160	473	338	5.16	2.81	50.5	107
Mountain Dew Energy	54	355	152	1.74	0.95	46	130

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Baskin Robbins Cappuccino Blast	234	710	330	7.55	4.11	–	–
Brewed Coffee	163	237	688	5.26	2.86	–	–
Decaffeinated Brewed Coffee	6	237	25	0.19	0.11	–	–
Instant Coffee	57	237	241	1.84	1.00	–	–
Instant Decaffeinated Coffee	3	237	13	0.10	0.05	–	–
Costa Flat White	277	450	616	8.94	4.86	–	–
McDonald's Coffee	145	473	307	4.68	2.54	–	–
Starbucks Caffè Latte (Short)	75	236	318	2.41	1.32	–	–
Caffè Nero Regular Americano	80	354	225	2.58	1.40	–	–

Table 2 presents an analysis of caffeine and sugar content in ED and coffee beverages, demonstrating substantial variability in stimulant exposure across commercially available products. Among the ED evaluated, Rockstar Zero Carb exhibited the highest caffeine concentration (507 mg/L) and the highest estimated caffeine exposure for both 10-year-old and 16-year-old consumers, indicating a potentially elevated risk of excessive caffeine intake in younger populations. Similarly, NOS, Monster, Rockstar, and Relentless contained high caffeine levels exceeding 300 mg/L, along with considerable sugar content. Sugared ED, such as Wicked, Rockstar, NOS, and Mountain Dew Energy, also demonstrated notably high sugar contents, ranging from 46 g to 63.2 g per serving. These levels substantially exceed recommended daily sugar intake values for children and adolescents and may contribute to obesity, metabolic disorders, and dental health complications when consumed frequently.

In contrast, sugar-free formulations, including Red Bull Sugar-Free, Red Bull Total Zero, Monster Absolute Zero, and Rockstar Zero Carb, contained negligible or no sugar while still maintaining relatively high caffeine concentrations. This finding suggests that the absence of sugar does not necessarily reduce stimulant exposure. Among coffee beverages, Costa Flat White and Baskin-Robbins Cappuccino Blast showed the highest estimated caffeine exposure levels, particularly for younger individuals. Brewed coffee also demonstrated a very high caffeine concentration per liter despite smaller serving sizes. Decaffeinated beverages contained minimal caffeine levels and therefore represent substantially lower stimulant exposure. Overall, the findings indicate that several commercially available ED and coffee beverages contain caffeine levels that can exceed recommended intake thresholds for children and adolescents, especially when consumed in large serving sizes. These data emphasize the importance of consumer awareness, clearer labeling practices, and public health strategies reducing excessive caffeine and sugar consumption among young individuals.

Herbal Supplements

Ingredients like ginkgo, ginseng, yerba mate, and biloba. These substances are typically added to achieve the intended mental stimulation, although scientific support for these effects is limited.

Sugars & Sweeteners

ED usually contains large amounts of sugar, ranging from 21 g to 63 g per serving. 5 to 16 teaspoons of sugar per can [4]. The sugar content is mainly in the form of sucrose, glucose, or high fructose corn syrup Glucuronolactone is a naturally occurring carbohydrate and a metabolite of glucose produced by the human liver. It is widely used as a key ingredient in ED, pre-workouts, and sports supplements to promote mental sharpness, detoxify the body, and reduce fatigue

B vitamins

Used in large doses - especially vitamins B6 and B12 - to help the body produce energy. Low levels of B vitamins can lead to fatigue, poor concentration, and slower metabolism. B12 exists as methyl cobalamin because its better absorption and ability to maintain neurological health make it the preferred choice for modern energy drink formulation. The body needs B vitamins because they are essential for energy production as part of the balanced formula of the energy drink.

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Amino Acids & Derivatives

Taurine

The most ubiquitous amino acid in ED (e.g., Red Bull, Monster). It supports cardiac function, aids in nerve transmission, and helps regulate cellular stress.

L-Carnitine

Often found in "workout" or weight management drinks, this amino acid facilitates the transport of fatty acids into cells to be burned for energy. Thus, it is included in ED to improve metabolism and for muscle recovery.

BCAAs (Branched-Chain Amino Acids)

Leucine, isoleucine, and valine are added to workout beverages to help accelerate muscle repair, prevent post-exercise exhaustion, and provide an energy source during extreme activity.

L-Tyrosine: A building block for neurotransmitters like dopamine. It is commonly included in nootropic-style ED to improve mental focus and alertness under stress.

Glutamine: A non-essential amino acid used in sports beverages to support immune function and heal muscle tissue post-exercise

L-Theanine: Focus and Calm Enhancer**,** L-Theanine, a naturally occurring amino acid found in green tea, is added to ED today because it promotes relaxation and enhances focus. It also supports neurotransmitters such as gamma-aminobutyric acid (GABA) and dopamine, positively affecting the body and promoting relaxation and mental clarity.

Physiological Effects and Health Consequences

EDs exert their physiological effects primarily through caffeine and other stimulant compounds. Adolescents are particularly vulnerable because their neurological, endocrine, and cardiovascular systems are still developing. High caffeine intake is associated with acute and chronic daily headaches by stimulating a pro-nociceptive state of cortical hyperexcitability. Four caffeine-induced psychiatric disorders have been recognized by the Diagnostic and Statistical Manual of Mental Disorders, including caffeine intoxication, caffeine-induced anxiety, caffeine-induced sleep disorder, and caffeine-related disorder. (16) A study of adolescents between 15 and 16 years of age demonstrated a strong correlation between caffeine intake and violent behavior as well as conduct disorders. (17)

In vitro studies found that a combination of caffeine, taurine, and guarana may promote and enhance apoptosis by reducing both superoxide dismutase and catalase activities in human neuronal SH-SY5Y cells

Cardiovascular Effects

Caffeine stimulates the sympathetic nervous system and increases catecholamine release. While they are often marketed as a way to increase energy and improve performance, they can also have serious cardiovascular consequences. Studies have reported elevations in blood pressure, heart rate, QT interval prolongation, endothelial dysfunction, arrhythmias, atrial fibrillation, ventricular tachycardia, and rare cases of sudden cardiac death [2, 3,5,8,29].

Recent studies have found that ED consumption is associated with increased blood pressure, platelet aggregation, and arrhythmias. Several case reports have described individuals who experienced ventricular fibrillation, myocardial infarction, and cardiac arrest shortly after consuming Eds (2). Several reports have indicated that ED may contribute to ischemic stroke and trigger seizures. (18) Hallucinations may be observed in individuals consuming more than 300 mg of caffeine daily. (19) Furthermore, the elevated cortisol levels that follow caffeine consumption may explain this. Cortisol enhances the physiological effects of stress, resulting in a greater tendency for the subjects to hallucinate. (20). Excessive taurine intake, especially when combined with caffeine in ED, has been linked to side effects such as increased heart rate, high blood pressure, anxiety, and sleep disturbances.

While taurine is generally considered safe in moderate amounts, consuming large doses from supplements or multiple ED per day may stress the cardiovascular and central nervous systems. Anyone with underlying health conditions should be cautious and consult a healthcare professional [30,31,32]

Neurological and Cognitive Effects

Acute caffeine consumption may improve alertness and reaction time; however, excessive intake is associated with headaches, tremors, dizziness, nervousness, agitation, and seizures. Chronic exposure during adolescence may interfere with neurodevelopment and executive functioning [6,7,33,34].

Sleep Disturbances

Regular consumers experience reduced sleep duration, delayed sleep onset, insomnia, daytime fatigue, and impaired academic performance. Sleep disruption is one of the most consistently reported adverse effects among adolescents [1,35,36].

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Mental Health and Behavioral Consequences
Multiple studies have linked energy drink consumption with anxiety, depression, stress, mood disorders, aggression, impulsivity, risk-taking behavior, and substance use [7,8,24,37]. Elevated cortisol levels may contribute to chronic psychological stress.

Metabolic Effects and Obesity
High sugar content contributes to excessive caloric intake, obesity, insulin resistance, metabolic syndrome, and type 2 diabetes [15,18,38]. Frequent consumption is also associated with poorer dietary quality. Therefore, high energy drink intake may increase the risk of obesity and type 2 diabetes. In addition, the high sugar content in ED may reduce the activity, diversity, and gene expression of intestinal bacteria, resulting in an increased risk of obesity and metabolic syndrome. Acute caffeine intake decreases insulin sensitivity, which could explain the rise in blood glucose levels after energy drink consumption documented in some studies. Beaudoin et al. demonstrated that caffeine intake reduces insulin sensitivity in a dose-dependent manner, with 5.8% increase in insulin for each mg/kg increase in caffeine [39,40] A case has been reported of a woman who presented with jaundice, abdominal pain, and highly elevated liver enzymes following energy drink overconsumption. Huang et al. reported the same finding in a 36-year-old man.

Renal and Hydration Effects
Excessive caffeine intake may increase fluid loss and contribute to dehydration, electrolyte imbalance, and renal stress, particularly during exercise [14,22]. The caffeine in ED has been shown to promote urination. (28) Therefore, ED should be avoided during prolonged exercise in hot environments due to the potential for dehydration. Studies have indicated that even a 1.5% dehydration level during prolonged exercise can lead to increased body temperature, heart rate, and feelings of fatigue. (29)

Hepatic Effects
Chronic intake of sugar-rich ED may promote fatty liver disease, oxidative stress, inflammation, and structural liver changes [22].

Gastrointestinal and Dental Consequences
ED may increase gastric acid secretion, contributing to reflux, gastritis, nausea, and abdominal discomfort. Their acidic pH and sugar content accelerate enamel erosion and dental caries [17,26].

Bone Health and Growth
Excessive caffeine intake may impair calcium absorption and increase calcium excretion, potentially affecting bone mineralization and skeletal development during adolescence [4].

Immune and Hormonal Effects: Chronic caffeine exposure may elevate cortisol levels, suppress immune responses, alter inflammatory pathways, and disrupt hormonal regulation and growth processes [3,5]. Overall, current evidence indicates that habitual energy drink consumption may adversely affect multiple organ systems simultaneously and represents a significant public health concern for adolescents [1,5,30].

Taurine and Leukemia Risk
Recent research has begun to show a complex link between taurine and cancer cell growth, especially in blood cancers like leukemia. Some in vitro studies suggest that taurine might serve as a source of energy for certain cancer cells, helping them grow and multiply faster. Taurine is naturally made in the human body and is important for normal cell functions. However, the high amounts of taurine found in some ED and supplements have raised questions about whether it could unintentionally help cancer cells grow. Taurine itself does not cause cancer. The concern is about how taurine might affect the growth of cancer once it has already started. For people with leukemia, too much taurine from supplements or ED could create conditions that allow cancer cells to grow more quickly. These findings suggest that people with blood cancers or those at higher risk should be careful and talk to their doctor before using products that contain taurine [4,42,43].

Evidence from Recent Research
Studies published between 2019 and 2026 consistently report associations between energy drink consumption and obesity, poor sleep quality, anxiety, depression, cardiovascular abnormalities, reduced academic performance, cancer, and behavioral problems [1,5,7,30]. Several investigations have also identified increased aggressive behavior and impulsivity among frequent consumers [31].
This observation has been supported by the findings that consuming ED reduces endothelial function and stimulates platelet activity through arachidonic acid-induced platelet aggregation in healthy young adults. In addition, Recent reports have demonstrated a relationship between energy drink overconsumption and arterial dilatation, aneurysm formation, dissection, and rupture of large arteries. This situation is

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exacerbated by acidic additives and oxidative stress caused by sugar. Worryingly, combining ED with alcohol blocks anesthesia, promoting traumatic injury and accelerating damage to the liver and nerve cells [45]
L-Theanine, along with caffeine, calms the nervous system's activity while increasing focus. It is added to energy drink ingredients for sustained, powerful, and smooth energy. However, studies are needed to determine which individuals are highly susceptible and the underlying mechanism by which ED cause hepatic injury [45].

Public Health Implications
The aggressive marketing of ED toward young people contributes to their widespread use. Educational interventions, warning labels, age restrictions, and awareness campaigns may help reduce consumption and improve health outcomes among adolescents [9].

Healthy Alternatives
Healthier alternatives include water, milk, natural fruit juices, herbal teas, and nutrient-rich snacks. Adequate sleep, balanced nutrition, and regular physical activity remain the safest methods for maintaining energy levels and cognitive performance.

Conclusion
Although ED may provide temporary improvements in alertness and performance, excessive consumption is associated with substantial cardiovascular, neurological, psychological, metabolic, dental, carcinogenic, and developmental consequences. Increased awareness, improved regulation, and targeted educational interventions are necessary to protect adolescent health. The year 2026 should see brands increasingly selecting natural energy drink ingredients, which include green tea extract, coffee bean extract, and guarana. These sources provide smoother energy release and support the growing demand for clean-label ED.

Conflict of interest. Nil

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