Health Effects of Energy Drinks on Children, Adolescents, and Young Adults

OBJECTIVE: To review the effects, adverse consequences, and extent of energy-drink consumption among children, adolescents, and young adults.

METHODS: We searched PubMed and Google using “energy drink,” “sports drink,” “guarana,” “caffeine,” “taurine,” “ADHD,” “diabetes,” “children,” “adolescents,” “insulin,” “eating disorders,” and “poison control center” to identify articles related to energy drinks. Manufacturer Web sites were reviewed for product information.

RESULTS: According to self-report surveys, energy drinks are consumed by 30% to 50% of adolescents and young adults. Frequently containing high and unregulated amounts of caffeine, these drinks have been reported in association with serious adverse effects, especially in children, adolescents, and young adults with seizures, diabetes, cardiac abnormalities, or mood and behavioral disorders or those who take certain medications. Of the 5448 US caffeine overdoses reported in 2007, 46% occurred in those younger than 19 years. Several countries and states have debated or restricted their sales and advertising.

CONCLUSIONS: Energy drinks have no therapeutic benefit, and many ingredients are understudied and not regulated. The known and unknown pharmacology of agents included in such drinks, combined with reports of toxicity, raises concern for potentially serious adverse effects in association with energy-drink use. In the short-term, pediatricians need to be aware of the possible effects of energy drinks in vulnerable populations and screen for consumption to educate families. Long-term research should aim to understand the effects in at-risk populations. Toxicity surveillance should be improved, and regulations of energy-drink sales and consumption should be based on appropriate research. Pediatrics 2011;127:511–528
“Energy drinks” are beverages that contain caffeine, taurine, vitamins, herbal supplements, and sugar or sweeteners and are marketed to improve energy, weight loss, stamina, athletic performance, and concentration.1–3 Energy drinks are available in >140 countries and are the fastest growing US beverage market; in 2011, sales are expected to top $9 billion.4–10 Half of the energy-drink market consists of children (<12 years old), adolescents (12–18 years old), and young adults (19–25 years old).7–10

Although healthy people can tolerate caffeine in moderation, heavy caffeine consumption, such as drinking energy drinks, has been associated with even more serious consequences such as seizures, mania, stroke, and sudden death.6–8,12–14 Numerous reports exist in the popular media, and there are a handful of case reports in the literature that associate such adverse events with energy-drink consumption; it is prudent to investigate the validity of such claims (Appendix). Children, especially those with cardiovascular, renal, or liver disease, seizures, diabetes, mood and behavioral disorders, or hyperthyroidism or those who take certain medications, may be at higher risk for adverse events from energy-drink consumption.6–8,14–24 Although the US Food and Drug Administration (FDA) limits caffeine content in soft drinks, which are categorized as food, there is no such regulation of energy drinks, which are classified as dietary supplements.1–3

Despite the large, unregulated market for energy drinks and reports in the literature and popular media of serious adverse events associated with their consumption, research into their use and effects has been sparse.25 However, schools, states, and countries increasingly are exploring content and sales regulations of these drinks.1,8,13,26–35

Given the rapidly growing market and popularity among youth, we reviewed the literature to (1) determine what energy drinks are, (2) compile consumption data of energy drinks by children, adolescents, and young adults, (3) compile caffeine and energy-drink overdose data, (4) examine the physiologic effects of the ingredients in energy drinks, (5) identify potential problems of energy drinks among children and adolescents, (6) assess the marketing of energy drinks, (7) report current regulation of energy drinks, and (8) propose educational, research, and regulatory recommendations.

METHODS

We searched PubMed by using “energy drink,” “sports drink,” “guarana,” “caffeine,” “taurine,” “ADHD” (attention-deficit/hyperactivity disorder), “diabetes,” “children,” “adolescents,” “insulin,” “eating disorders,” and “poison control center” singly or in combination. We limited searches to English-language and foreign-language articles with English-language abstracts and selected articles by relevance to energy-drink use in children and adolescents. We similarly searched Google for print and trade media. We reviewed articles and Internet sources by the above search through June 2010 and updated sections as new information became available through January 2011.

RESULTS

Two-thirds of the 121 references we found on energy drinks were in the scientific literature, although reports by government agencies and interest groups also contained much useful information (Table 1). Most information came from the United States, but European, Canadian, Australian, New Zealand, and Chinese sources are also represented.

DISCUSSION

What Are Energy Drinks?

Energy drinks may contain caffeine, taurine, sugars and sweeteners, herbal supplements, and other ingredients (Table 2) and are distinct from sports drinks and vitamin waters (Table 3).6,8 In 2008, the National Federation of State High School Associations, while recommending water and sports drinks for rehydration, specifically did not recommend energy drinks and cited potential risks, the absence of benefit, and drug interactions (Table 4).26,37

Caffeine is the main active ingredient in energy drinks; many of them contain 70 to 80 mg per 8-oz serving (3–3 times the concentration in cola drinks) (Table 5).6,31 Caffeine content can be nearly 5 times greater than that in 8 oz of cola drinks when packaged as “energy shots” (0.8–3 oz) or as 16-oz drinks.5,29,38

Energy drinks often contain additional amounts of caffeine through additives, including guarana, kola nut, yerba mate, and cocoa.5,7,14,25 Guarana (Paullinia cupana) is a plant that contains caffeine, theobromine (a chronotrope), and theophylline (an inotrope).5,10 Each gram of guarana can contain 40 to 80 mg of caffeine, and it has a potentially longer half-life because of interactions with other plant compounds.7,14 Manufacturers are not required to list the caffeine content from these ingredients.7,14 Thus, the actual caffeine dose in a single serving may exceed that listed.9,29

Consumption of Energy Drinks by Children, Adolescents, and Young Adults

In the United States, adolescent caffeine intake averages 60 to 70 mg/day and ranges up to 800 mg/day.24,40 Most caffeine comes from soda; however,
<table>
<thead>
<tr>
<th>Source Description</th>
<th>No. of Results</th>
<th>Main Topics</th>
<th>Source Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary literature</td>
<td>81</td>
<td>Energy drinks are a growing problem; safety issues with energy drinks; stimulant adverse effects; caffeine dependence; caffeine and fluid-electrolyte balance; caffeine and exercise performance; caffeine and mental performance; caffeine and apnea of prematurity; caffeine and bronchopulmonary dysplasia; caffeine and coronary heart disease; herb adverse effects; adolescents with ADHD and misuse of medication; ADHD and substance use; cardiovascular effects of antidepressants in children and adolescents; caffeine consumption and eating disorders; caffeine and bone gain in children and adolescents; incidence of pediatric cardiomyopathy; frequency of myocardial injury in children; epidemiology of hypertrophic cardiomyopathy</td>
<td>US, Poland, United Kingdom, Germany, China</td>
</tr>
<tr>
<td>Systematic reviews</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review articles</td>
<td>36</td>
<td>Cognitive and physiological effects of energy drinks; caffeine and exercise performance, thermoregulation, and fluid-electrolyte balance; energy-drink effects on hemodynamic and electrocardiographic parameters in young adults; caffeine effects in children; gender differences and caffeinated beverages; taurine and cardiac parameters; energy drinks and platelet and endothelial function; eye-tracking in adolescents viewing advertisements</td>
<td>United States, United Kingdom, Germany</td>
</tr>
<tr>
<td>Randomized controlled trials</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental studies</td>
<td>16</td>
<td>Caffeine and sleep patterns in children; caffeine exposure in children, adolescents, and young adults</td>
<td>United States</td>
</tr>
<tr>
<td>Cohort studies</td>
<td>2</td>
<td>Consumption by college students; consumption of caffeinated beverages by adolescents; energy drinks and risk-taking behavior; survey of obstetrician/gynecologist caffeine knowledge</td>
<td>United States</td>
</tr>
<tr>
<td>Surveys</td>
<td>4</td>
<td>Consumption by adolescents; energy drinks and risk-taking behavior; survey of obstetrician/gynecologist caffeine knowledge</td>
<td>United States, Germany</td>
</tr>
<tr>
<td>Case reports</td>
<td>8</td>
<td>Caffeine-induced psychosis; energy drinks and seizures; cardiac arrest after energy-drink consumption; cardiac arrhythmias associated with energy-drink consumption; caffeine fatalities; Red Bull and postural tachycardia; cardiomyopathy and pericarditis after methylphenidate; psychosis after energy-drink consumption</td>
<td>United States</td>
</tr>
<tr>
<td>Perspectives</td>
<td>10</td>
<td>Caution reduces long-term health risks; pediatric cardiology; cardiovascular adverse effects of stimulants; prevention of hypertension; stimulants and sudden death; cardiovascular disease and stimulants in children; sugary beverages and childhood obesity; fluid replacement and exercise</td>
<td>United States</td>
</tr>
<tr>
<td>Basic science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal studies</td>
<td>5</td>
<td>Stimulants and insulin-stimulated glucose uptake in rats; adenosine receptors in rats; structural changes in rat heart tissue after oral methylphenidate</td>
<td>United States</td>
</tr>
<tr>
<td>Human studies</td>
<td>2</td>
<td>Caffeine modulates gene expression; guarana and platelet function</td>
<td>United States</td>
</tr>
<tr>
<td>Government agency reports</td>
<td>10</td>
<td>FDA overview of dietary supplements; energy drinks/high-caffeine beverages; caffeinated beverages and obesity; dietary supplements and military personnel; German assessment of energy drinks; Canadian assessment of energy drinks; health risks of energy shots; Poison Control Center data</td>
<td>Australia, Canada, European Germany, New Zealand, United States</td>
</tr>
<tr>
<td>Interest groups</td>
<td>3</td>
<td>Alcoholic energy drinks and youth; nutrition and energy drinks</td>
<td>United States</td>
</tr>
<tr>
<td>Popular media</td>
<td>27</td>
<td>Overuse of energy drinks and health consequences; school bans on energy drinks; racial differences in caffeine metabolism; energy-drink dangers for youth; restriction of drugs in youth; preparticipation screening and congenital heart defects; regulation of energy drinks; Hong Kong’s ban of Red Bull; questioning dietary supplements</td>
<td>United States</td>
</tr>
<tr>
<td>Newspaper articles</td>
<td>14</td>
<td>Overuse of energy drinks and health consequences; school bans on energy drinks; racial differences in caffeine metabolism; energy-drink dangers for youth; restriction of drugs in youth; preparticipation screening and congenital heart defects; regulation of energy drinks; Hong Kong’s ban of Red Bull; questioning dietary supplements</td>
<td>United States</td>
</tr>
<tr>
<td>Web sites</td>
<td>12</td>
<td>Energy-drink sales; French ban on Red Bull; Germany questions energy-drink safety; a school’s ban on energy drinks; marketing of energy drinks; high caffeine levels in energy drinks in Australia; Ireland’s review of the safety of energy drinks; Dutch schools’ ban on Red Bull; preparticipation sports physicals</td>
<td>Holland, United Kingdom, United States</td>
</tr>
<tr>
<td>Books</td>
<td>1</td>
<td>History of energy drinks and health consequences</td>
<td>United States</td>
</tr>
<tr>
<td>Total</td>
<td>121</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
energy drinks are becoming increasingly popular.[7,24,41,42] The following self-report studies have examined energy-drink consumption by children, adolescents, and young adults.[7,24,41,42]

One study found that 28% of 12- to 14-year-olds, 31% of 12- to 17-year-olds, and 34% of 18- to 24-year-olds reported regularly consuming energy drinks.[5,43] Shortly after energy drinks were approved in Germany, a study of 1265 adolescents found that 94% were aware of energy drinks, 53% had tried them, 23% drank <1 can per week, and 3% drank 1 to 7 cans per week.[44] Among 10- to 13-year-olds, 31% of girls and 50% of boys had tried energy drinks, and 5% of girls and 23% of boys reported drinking them regularly but at a rate of <1 can per week.[44]

Most children

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Description</th>
<th>Therapeutic Uses</th>
<th>Purported Effect From Energy Drinks</th>
<th>Adverse Effects (due to Idiosyncratic or Excessive Dosage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caffeine</td>
<td>An adenosine receptor antagonist: a central nervous system stimulant</td>
<td>As caffeine citrate, used to treat apnea and bronchopulmonary dysplasia in premature infants</td>
<td>Increases exercise endurance and improves cognition and mood when fatigued or sleep-deprived</td>
<td>Nervousness, irritability, anxiety, insomnia, tachycardia, palpitations, upset stomach, vomiting, abdominal pain, rigidity, hypokalemia, altered consciousness, paralysis, hallucinations, increased intracranial pressure, cerebral edema, seizures, rhabdomyolysis, supraventricular and ventricular tachyarrhythmias</td>
</tr>
<tr>
<td>Guarana</td>
<td>A South American plant that contains large amounts of caffeine, theobromine, and theophylline (a chronotrope and an inotrope) and tannins</td>
<td>None known</td>
<td>Stimulant, mainly through the effects of caffeine, and weight loss</td>
<td>Generally considered safe by the FDA Center for Food Safety and Applied Nutrition</td>
</tr>
<tr>
<td>Taurine</td>
<td>An abundant amino acid in the central nervous system; acts in neural growth and protection, cell metabolism, osmoregulation, antioxidation, and glycolysis; estimated daily intake is 400 mg/d</td>
<td>Infant formula has been supplemented with taurine since the 1980s because of evidence that it promotes healthy development; used to treat alcohol withdrawal, congestive heart failure, cystic fibrosis, palpitations/dysrhythmias, hypertension, diabetes, seizure disorders, hepatitis</td>
<td>Marketed to promote eye and biliary health and to prevent congestive heart failure by lowering blood pressure while improving cardiac contractility</td>
<td>Generally considered safe by the FDA</td>
</tr>
<tr>
<td>L-Carnitine</td>
<td>An amino acid involved in β-oxidation of fatty acids</td>
<td>Used as a therapeutic supplement in congenital and acquired-deficiency states, end-stage renal disease, valproate toxicity, and dementia; increases attention and decreases hyperactivity in certain populations of children; nonstimulant L-acetyl-carnitine is used to treat ADHD in boys with fragile X syndrome and, in 1 study, children with typical ADHD; it may also protect against heart disease</td>
<td>Added to promote fat metabolism and increase endurance</td>
<td>In high doses, can cause nausea, vomiting, abdominal pain, and diarrhea; has been reported to cause seizures in patients with no known disease and to increase seizure frequency in patients with seizure disorder</td>
</tr>
<tr>
<td>Ginseng</td>
<td>An East Asian herb</td>
<td>Believed to improve memory, increase stamina, and stimulate immune function</td>
<td>Improve physical performance</td>
<td>Reported symptoms of ginseng toxicity include diarrhea, vaginal bleeding, headache, vertigo, mania, hypertension, rashes, insomnia, irritability, Stevens-Johnson syndrome, and agranulocytosis, some of these symptoms may be related to contaminants, such as phenylbutazone and aminopyrine, used in its processing</td>
</tr>
<tr>
<td>Yohimbine</td>
<td>An alkaloid found in the plants <strong>Pausinystalia yohimbe</strong> and <strong>Rauwolfia serpentina</strong></td>
<td>An herbal supplement believed to be an aphrodisiac and to relieve chest pain, diabetic complications, depression, and erectile dysfunction</td>
<td>Increase energy, metabolism, and stamina; promotes well-being</td>
<td>Can cause hypertension at usual doses and hypotension at high doses; tachycardia, death</td>
</tr>
</tbody>
</table>
in the study consumed energy drinks in moderation, but a small group consumed extreme amounts.44 A survey of 496 college students found that 51% of those surveyed regularly consumed >1 energy drink per month; the majority of them habitually drank energy drinks several times per week.8 Insufficient sleep (67%) and the
desire to increase energy (65%) were the most common reasons for use. In this study, 54% of the respondents reported mixing energy drinks with alcohol, and 49% drank ≥3 of them while partying. Another study of 795 college students found that 39% of the respondents had consumed an energy drink in the previous month and that, on average, men drank energy drinks 2.5 days/month, whereas women drank 1.2 days/month.45

The estimated caffeine exposure of consuming energy drinks or energy shots was calculated for New Zealand children (5–12 years old), teenagers (13–19 years old), and young men (19–24 years old) (Figs 1–3). After consuming a single retail unit, 70% of the children and 40% of the teenagers who consumed caffeine were estimated to have exceeded the adverse-effect level of 3 mg/kg body weight per day beyond their baseline dietary exposure.46 An average child, teenager, or young man would all, on average, exceed the adverse-effect level after consuming a single retail unit of energy drink/energy shot above their baseline dietary caffeine exposure.46

**Caffeine and Energy-Drink Overdoses**

US poison centers have not tracked the prevalence of overdoses attributed to energy drinks, because exposures were coded as “caffeine” or “multisubstance exposures” and combined with other caffeine sources (Table 6) (American Association of Poison Control Centers Board of Directors, personal communication, 2010).47 Energy drinks were recently given unique reporting codes, so their toxicity can now be tracked (American Association of Poison Control Centers Board of Directors, personal communication, 2010).47 Germany has tracked energy-drink–related incidents since 2002.33 Reported outcomes include liver damage...
Physiologic Effects of the Ingredients in Energy Drinks

Caffeine Pharmacology and Physiology

Caffeine, the most commonly used psychoactive drug worldwide, may be the only psychoactive drug legally available over-the-counter to children.39,48 Caffeine is an adenosine and benzodiazepine receptor antagonist, phosphodiesterase inhibitor, and central nervous system stimulant.29,38,49 In healthy adults, a caffeine intake of 400 mg/day is considered safe; acute clinical toxicity begins at 1 g, and 5 to 10 g can be lethal.29

Physiologically, caffeine causes coronary and cerebral vasoconstriction, relaxes smooth muscle, stimulates skeletal muscle, has cardiac chronotropic and inotropic effects, reduces insulin sensitivity, and modulates gene expression in premature neonates.9,29,50–52 Large amounts of caffeine increase urine flow and sweat ex-
cretion and alter blood electrolyte levels.\textsuperscript{11,53} Although caffeine is a mild diuretic, consumption of \( \leq 500 \text{ mg/day} \) does not cause dehydration or chronic water imbalance.\textsuperscript{54,55} Caffeine is a ventilatory stimulant with anti-inflammatory and bronchoprotective effects.\textsuperscript{56} Caffeine has been linked to dyspnea on exertion from central and peripheral chemoreceptor stimulation.\textsuperscript{56} In addition, increased breathing work may divert blood flow away from locomotor muscles and negate any ergogenic advantage.\textsuperscript{56} Caffeine’s cardiovascular effects include decreased heart rate from stimulation of medullary vagal nuclei and increased blood pressure.\textsuperscript{24,57–61}

Adults who consume low-to-moderate amounts of caffeine (1–3 mg/kg or 12.5–100 mg/day) have improved exercise endurance, cognition, reaction time, and mood with sleep deprivation.\textsuperscript{9,24,56,62} However, these studies typically involve habitual caffeine consumers, and results reflect withdrawal-symptom reversal.\textsuperscript{58} Consuming 4 to 12 mg/kg of caffeine has been associated with undesirable symptoms, including anxiety and jitteriness.\textsuperscript{63} Headache and fatigue, common withdrawal symptoms, can occur after short-term, high-dose use.\textsuperscript{64} Caffeine intoxication is a clinical syndrome of nervousness, irritability, anxiety, insomnia, tremor, tachycardia, palpitations, and upset stomach.\textsuperscript{6,7,9,14,26,65} Additional adverse effects include vomiting and abdominal pain, hypokalemia, hallucinations, increased intracranial pressure, cerebral edema, stroke, paralysis, rhabdomyolysis, altered consciousness, rigidity, seizures, arrhythmias, and death.\textsuperscript{1,2,8,29,48}

Caffeine intakes of \( \geq 300 \text{ mg/day} \) have been associated with miscarriage and low birth weight.\textsuperscript{38,66,67} Long-term caffeine consumption relates to a lower

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{A, Cumulative probability curves of children (5–12 years old) consuming 1 to 4 retail units of energy drinks or energy shots in addition to baseline dietary exposure.\textsuperscript{46} B, Cumulative probability curve for teenagers (13–19 years old) consuming 1 to 4 retail units of energy drinks or energy shots in addition to baseline dietary exposure.\textsuperscript{46} C, Cumulative probability curve of young males (19–24 years old) consuming 1 to 4 retail units of energy drinks or energy shots in addition to baseline dietary exposure.\textsuperscript{46} Caffeine-exposure units are mg/kg body weight per day. An adverse-effect level of 3 mg/kg body weight per day is shown as a reference point. The portion of each curve to the right of the adverse-effect level represents the proportion of the population potentially at risk from adverse effects of caffeine. The exposure of any percentile may be read off the x-axis by extrapolating from the intersection of the selected percentile on the y-axis with the curve of 1, 2, 3, or 4 retail units consumed; cumulative probability = 0.2 represents the 20th percentile, 0.4 = 40th percentile, etc. Reproduced with permission from David Crowe, manager of consumer communications for the New Zealand Food Safety Authority.}
\end{figure}
risk of Parkinson disease and a slower age-related cognitive decline.58

Effects of Caffeine in Children and Adolescents

Adolescent and child caffeine consumption should not exceed 100 mg/day and 2.5 mg/kg per day, respectively.7,38,63 For example, 8 oz of Red Bull (Fuschl am See, Austria) provides 77 mg of caffeine, or 1.1 mg/kg for a 70-kg male or 2.2 mg/kg for a 35-kg preteen.40 Whether the effects of caffeine in adults can be generalized to children remains unclear.63 In a study of 26 boys and 26 men, the same dose of caffeine affected blood pressure similarly, but heart rate was significantly lowered in boys, whereas there was no effect on heart rate in men.68 Boys also exhibited increased motor activity and speech rates and decreased reaction times than did men.69

Caffeine can improve attention, but it also increases blood pressure and sleep disturbances in children.24,63,70,71 After cessation in children who habitually consume caffeine, attention decreases and reaction time increases transiently.24,39 Similarly, reaction time has been shown to decrease as the dose of caffeine in children increases.24

In a study of 9- to 11-year-olds with habitual (mean intake: 109 mg/day) and low (mean intake: 12 mg/day) caffeine consumption given 50 mg of caffeine after overnight abstention, habitual caffeine users reported withdrawal-symptom (headache and dulled cognition) reversal. The children who did not habitually consume caffeine reported no marked changes in cognitive performance, alertness, or headache.63

Caffeine may affect future food and beverage preferences by acting on the developing child’s brain reward-and-addiction center; this effect may be gender specific.6 A study of 12- to 17-year-olds revealed that boys found caffeinated soda more reinforcing than did girls regardless of usual caffeine consumption.72

Physiologic Effects of Other Ingredients in Energy Drinks and Potential Synergistic Effects

Popular media and case reports have associated adverse events with energy-drink consumption (Appendix). Yet, few studies have examined the physiologic effects of individual ingredients or potential synergistic effects; furthermore, results of experimental studies have been inconclusive and occasionally contradictory.24,25,59,73

Some studies of adults revealed improved mental alertness, reaction times, and concentration with energy drinks59,74; others revealed no improvement compared with caffeine or glucose alone.73 One study of 14 young adults compared a complete energy-drink mixture to the glucose fraction, the caffeine fraction, and the herbal fraction.59 Although individual components did not enhance cognition, the combined ingredients did.59 Caffeine and taurine combined may synergistically decrease heart rate initially; one study found that 70 minutes after consumption, heart rate returned to normal and blood pressure increased.25,75 Taurine similarly produced a reflex bradycardia when injected into the rat cerebroventricular system.76 Another study of 15 healthy young adults in a 7-day trial in which they consumed 500 mL of an energy drink each day with 160 mg of caffeine and 2000 mg of taurine, reported an average increase in systolic blood pressure of 9 to 10 mm Hg and an average increased heart rate of 5 to 7 beats per minute 4 hours after consumption.25,38

Caffeine- and taurine-containing beverages increased left atrial contractility in 13 athletes, thereby increasing left ventricular end-diastolic volume and stroke volume.79 The caffeine-only group showed no changes in left ventricular function.76 Taurine may cause this increase in stroke volume by suppressing sympathetic nervous stimulation and influencing calcium stores in cardiac muscle.8 Results of human and animal studies have suggested that long-term taurine exposure may cause hypoglycemia25 but a decreased risk of coronary heart disease.77 In animal experiments, taurine also has shown anticonvulsive and epileptogenic properties.25

Among 50 young adults who drank one sugar-free energy drink, hemotologic and vascular effects included increased platelet aggregation and
mean arterial pressure and a decrease in endothelial function.79 Guarana has antiplatelet aggregation properties in vitro, but how it functions physiologically in energy drinks is unknown.79 A study of 20 healthy subjects revealed that caffeinated espresso had no effects on endothelial function.80 Caffeine alone did not affect platelet function.81

Ginseng, a common ingredient in many energy drinks, may lower blood glucose levels, but its actions in energy drinks are unclear.82

Potential Problems of Energy Drinks Among Children and Adolescents

Cardiovascular Effects of Energy Drinks on Children and Adolescents

High doses of caffeine may exacerbate cardiac conditions for which stimulants are contraindicated.17,18,84–86 Of particular concern are ion channelopathies and hypertrophic cardiomyopathy, the most prevalent genetic cardiomyopathy in children and young adults, because of the risk of hypertension, syncope, arrhythmias, and sudden death.11,86,87

Effects of Energy Drinks on Children and Adolescents With ADHD

ADHD occurs in 8% to 16% of US school-aged children and may be more prevalent in children with heart disease.88,89 Some 2.5 million US children take stimulants for ADHD, which may increase heart rate and blood pressure.89–91 Children with ADHD have higher rates of substance abuse, including the abuse of caffeine, which blocks the A2A adenosine receptors and thereby enhances the dopamine effect at the D2 dopamine receptor, similarly to the way guanfacine works for ADHD.92,93 As with the ADHD stimulants, the combined effects of energy drinks and antidepressants are unknown.94 For the subpopulation with methylphenidate cardiotoxicity, energy-drink use may increase cardiac events.95,96

Energy-Drink Use in Children and Adolescents With Eating Disorders

Children and adolescents with eating disorders, especially anorexia nervosa, may regularly consume high amounts of caffeine to counter caloric-restriction–associated fatigue, suppress appetite, and produce looser stools and some diuresis.71–100 The risk of cardiac dysrhythmias and intracardiac conduction abnormalities from high-caffeine energy drinks in children with eating disorders at higher risk for cardiac-related morbidity/mortality and electrolyte abnormalities is disconcerting.91–99

Effects on Caloric Intake and Diabetes

Because obesity is epidemic, caloric effects from energy-drink consumption become important. Additional calories may increase blood pressure, glucose levels, BMI, calcium deficiency, dental problems, depression, and low self-esteem.4,101,102 Sugar and caffeine may also synergistically increase postprandial hyperglycemia, which is of concern for children with diabetes.38,51,52

Effects on Bone Mineralization

Early adolescence is the time of maximal calcium deposition in bone, and caffeine interferes with intestinal calcium absorption.103,104 It remains controversial whether caffeine itself has the most marked effect on bone acquisition during adolescence or whether replacement of milk intake by caffeinated beverages is the leading contributor.103,104

Marketing of Energy Drinks

Youth-targeted marketing strategies date to 1987 when Red Bull was introduced in Austria.100 When it took 5 years to get permission to export Red Bull to Germany, rumors about its legality and dangerous effects helped fuel its popularity, and it became known as “speed in a can,” “liquid cocaine,” and a “legal drug.”100

Energy-drink marketing strategies include sporting event and athlete sponsorships, alcohol-alternative promotion, and product placement in media (including Facebook and video games) oriented to children, adolescents, and young adults.43,105 Newer alcoholic energy drinks, the cans of which resemble the nonalcoholic counterparts, target risk-taking youth.53

Contrasting with brand design is the voluntary fine-print warning label on some products, which state that they may not be safe for children, those who are sensitive to caffeine, or for pregnant or nursing women.106–107

Regulation of Energy Drinks

The FDA imposes a limit of 71 mg of caffeine per 12 fl oz of soda.1,2 Energy-drink manufacturers may circumvent this limit by claiming that their drinks are “natural dietary supplements.”1,2 Thus, safety determinations of energy drinks are made solely by the manufacturers, and there are no requirements for testing, warning labels, or restriction against sales or consumption by minors.1–3 In contrast, over-the-counter dedicated caffeine stimulants (eg, NoDoz [Novartis Consumer Health, Parsippany, NJ]) must list the minimum age for purchase (12 years), adverse effects, cautionary notes, recommended dose, and the total daily recommended dose of caffeine. In November 2009, the FDA asked manufacturers of alcoholic energy drinks to prove their safety.108 The US Senate is considering a bill that would require supplement manufacturers to register annually with the FDA and allow FDA recalls of supplements suspected of being unsafe. Ingredients may also be restricted to those that have already been approved by the FDA.109

Regulatory controversies also extend internationally (Table 7). When France
### Table 7 National and International Energy-Drink Regulations

<table>
<thead>
<tr>
<th>Country</th>
<th>Bans on Energy Drinks</th>
<th>Restrictions</th>
<th>Proposed or Attempted Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>—</td>
<td>—</td>
<td>Senate has proposed banning energy drinks in nightclubs⁵</td>
</tr>
<tr>
<td>Australia</td>
<td>Recently banned 5 energy drinks on the basis of a caffeine content of &gt;320 mg/L¹⁶</td>
<td>Requires warning labels, recommends a maximum daily consumption amount, and advises against mixing energy drinks with alcohol until further research has been conducted¹³</td>
<td>Classifying energy drinks as pharmaceutical products, which are regulated, has been proposed¹⁸</td>
</tr>
<tr>
<td>Canada</td>
<td>—</td>
<td>Requires warning labels, recommends a maximum daily consumption amount, and advises against mixing energy drinks with alcohol until further research has been conducted¹³</td>
<td>—</td>
</tr>
<tr>
<td>Denmark</td>
<td>Prohibits energy drinks entirely⁶,²⁶</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>European Food Safety Authority</td>
<td>—</td>
<td>Beverages that contain &gt;150 mg/L caffeine should be labeled “high caffeine content” and the exact amount present indicated on the label⁴²</td>
<td>—</td>
</tr>
<tr>
<td>European Union</td>
<td>—</td>
<td>Manufacturers are required to print on the packaging that the drinks have high caffeine content⁵</td>
<td>—</td>
</tr>
<tr>
<td>France</td>
<td>—</td>
<td>—</td>
<td>Banned Red Bull but recently removed the ban after assessment by the European Food Safety Authority⁵</td>
</tr>
<tr>
<td>Germany</td>
<td>11 of 16 German states banned Red Bull Cola because of trace amounts of cocaine¹¹¹</td>
<td>—</td>
<td>Stricter regulations on warning labels have been requested by the government²⁵; the German Federal Institute for Risk Assessment recommends that energy shots be banned because of the high risk of overdose³⁸</td>
</tr>
<tr>
<td>Ireland</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Netherlands</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Norway</td>
<td>—</td>
<td>Energy drinks can only be sold in pharmacies⁵,²⁵</td>
<td>Reviewed energy-drink safety; Ireland’s food-safety board has recommended that energy drinks be labeled as unsuitable for children &lt;16 y old and that a ban be placed on the promotion of Red Bull in sporting events and in combination with alcohol¹⁰,¹³²</td>
</tr>
<tr>
<td>Sweden</td>
<td>—</td>
<td>Sales to children &lt;15 y are banned, warning labels about consuming high caffeine after exercise and mixing energy drinks with alcohol are also present⁴</td>
<td>Drinks that contain &gt;150 mg/L of caffeine must be labeled “high caffeine content” and also must be labeled “not recommended for children, pregnant women, or people sensitive to caffeine”⁴⁴; energy drinks must also state the maximum amount to be used daily⁴⁶</td>
</tr>
<tr>
<td>Finland</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Turkey</td>
<td>Ban on all high-caffeine energy drinks⁹</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>—</td>
<td>—</td>
<td>The UK’s Committee on Toxicity investigated Red Bull and determined that it was safe for the general public but that children &lt;16 y old or people sensitive to caffeine should avoid drinks with high caffeine content⁵⁰</td>
</tr>
<tr>
<td>Uruguay</td>
<td>Prohibits energy drinks entirely²⁷¹</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>United States</td>
<td>—</td>
<td>The FDA has listed caffeine as generally recognized as safe in concentrations of &lt;200 mg/kg; in November 2009, the FDA announced plans to examine the safety of caffeinated alcoholic beverages⁴⁶</td>
<td>In 2008, Kentucky, Maine, and Michigan introduced legislation that would ban the sale of highly caffeinated drinks to children &lt;18 y old, but the bills were defeated²⁹; California is considering a bill to require special labels on alcoholic beverages to avoid confusion with nonalcoholic beverages⁴⁵</td>
</tr>
</tbody>
</table>
banned Red Bull, the manufacturers challenged the ban through the European Commission, which determined that the caffeine and taurine concentrations in energy drinks had not been proven to be health risks and ordered France to lift the ban; the European Food Safety Authority has encouraged international data-pooling to better assess risks in children, adolescents, and young adults.13,110 In 2008, authorities in Germany, Hong Kong, and Taiwan detected 0.15 μg per can of cocaine (average) in Red Bull Cola. Red Bull manufacturers insisted that active cocaine was removed from the coca leaf during processing and that the extract was used for flavoring. However, 11 of 16 German states banned the product.111

CONCLUSIONS

On the basis of this review, we conclude that (1) energy drinks have no therapeutic benefit, and both the known and unknown pharmacology of various ingredients, combined with reports of toxicity, suggest that these drinks may put some children at risk for serious adverse health effects;11,16,24,25,38. (2) Typically, energy drinks contain high levels of caffeine, taurine, and guarana, which have stimulant properties and cardiac and hematologic activity,7,8,11 but manufacturers claim that energy drinks are nutritional supplements, which shields them from the caffeine limits imposed on sodas and the safety testing and labeling required of pharmaceuticals7,8,11; (3) other ingredients vary, are understudied, and are not regulated; (4) youth-aimed marketing and risk-taking adolescent developmental tendencies combine to increase overdose potential; (5) high consumption is suggested by self-report surveys but is underdocumented in children (detrimental associations with energy-drink consumption have been reported globally in case reports and popular media7,8,11,25,31,38); and (6) interactions between compounds, additive and dose-dependent effects, long-term consequences, and dangers associated with risky behavior in children remain to be determined.5,14,25,38

EDUCATIONAL, RESEARCH, AND REGULATORY RECOMMENDATIONS

In the short-term, pediatric health care providers need to be aware of energy-drink consumption by children, adolescents, and young adults and the potentially dangerous consequences of inappropriate use.112 Diet and substance-use histories should include screening for episodic/chronic energy-drink consumption, both alone and with alcohol. Screening is especially important for athletes, children with high-risk behaviors, certain health conditions (eg, seizures, diabetes, hypertension, cardiac abnormalities), and children with behavioral changes, anxiety, poor nutrition, or sleep disturbances.11

For most children, adolescents, and young adults, safe levels of consumption have not been established. Yet, heavy use may be harmful or interact with medications and cause untoward adverse effects. Health care providers should educate families and children at risk for the potential adverse effects of energy drinks.

Routine high school athletic physicals do not identify everyone at risk for sudden cardiac death.11,113 Children with cardiac conditions should be counseled regarding the risks of caffeine-containing products, including irregular heart rhythms, syncope, dysrhythmias, and sudden death.17,18,85 Community partners, including schools, athletic groups, and regulatory bodies, also need to promote risk awareness.113 The fourth edition of the “Preparticipation Physical Evaluation” monograph will feature a revamped health questionnaire focused on cardiac health problems that may be exacerbated by physical activity; thus, adding questions about stimulant use, including energy-drink consumption, becomes important.113

Long-term research objectives should aim to better define maximum safe doses, the effects of chronic use, and effects in at-risk populations (eg, those with preexisting medical conditions, those who consume energy drinks during and after exercise, or those who consume them in combination with alcohol), and better documentation and tracking of adverse health effects.47 Unless research establishes energy-drink safety in children and adolescents, regulation, as with tobacco, alcohol, and prescription medications, is prudent.11

This approach is essential for reducing morbidity and mortality, encouraging research, and supporting families of children and young adults at risk for energy-drink overdose, behavioral changes, and acute/chronic health consequences.

ACKNOWLEDGMENTS

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<table>
<thead>
<tr>
<th>Source of Information</th>
<th>No. and Age Patients</th>
<th>Previous Health Conditions</th>
<th>Symptoms</th>
<th>Reported Association With Energy Drink</th>
<th>Ref No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journal articles/ case reports</td>
<td>One 25-y-old woman</td>
<td>Mitral valve prolapse</td>
<td>Unknown</td>
<td>Drank a bottle of Race 2005 Energy Blast with guarana and ginseng on the day that she had a cardiac arrest; the autopsy and toxicological screen results were negative except for a caffeine concentration of 19 mg/L in aortic blood</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>One 25-y-old man</td>
<td>None reported</td>
<td>Generalized seizures on 2 occasions over 4 mo; the seizures did not reoccur within 8 mo after abstaining from energy drinks</td>
<td>Reportedly drank energy drinks on an empty stomach; he reported consuming two 24-oz energy drinks 30–60 min before the seizure</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>One 31-y-old man</td>
<td>None reported</td>
<td>Rhabdomyolysis and acute kidney failure with tubular necrosis</td>
<td>Active football referee drank 3 cans of Red Bull before a 3000-m competition; the authors stated that the taurine could have caused the rhabdomyolysis from hyperosmolarity because the distance was relatively short compared with his normal training</td>
<td>25 and 38</td>
</tr>
<tr>
<td></td>
<td>One 43-y-old man</td>
<td>Paranoid-type schizophrenia and alcohol dependence in full, sustained remission</td>
<td>6-wk history of worsening paranoia, delusions, and agitation resulting in hospitalization</td>
<td>Started drinking energy drinks 2 wk before becoming symptomatic; consumption increased to 8–10 cans per d; the cessation of caffeine reportedly improved symptoms</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>One 47-y-old man</td>
<td>None reported</td>
<td>Delusions and paranoia; the psychosis resolved within 7 wk after reducing caffeine consumption</td>
<td>High caffeine intake</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>2 patients</td>
<td>Migraine headaches</td>
<td>Seizures</td>
<td>In 1 case, the energy drink was consumed on an empty stomach; in the other case, caffeine tablets were also consumed with the energy drink</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>2 depressed patients and 1 patient with no psychiatric illness</td>
<td>Started on ginseng for several months</td>
<td>Unknown</td>
<td>Mania, which resolved after stopping taking ginseng</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>One young professional volleyball player</td>
<td>None reported</td>
<td>Developed orthostatic intolerance, postural tachycardia, and syncope, which resolved after energy-drink consumption was stopped</td>
<td>4–5 cans of Red Bull per d</td>
<td>75</td>
</tr>
<tr>
<td>Newspaper articles</td>
<td>4 middle school students</td>
<td>None reported</td>
<td>All transported to the hospital with tachycardia, hypertension, paresthesia, diaphoresis, jitters/anxiety; hypokalemia and hyperglycemia were diagnosed in the emergency department</td>
<td>All 4 shared 1 can of Redline energy drink</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>7 high school students</td>
<td>None reported</td>
<td>Shortness of breath, heart palpitations, nausea; 2 students were treated in a hospital</td>
<td>SPIKE Shooter</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>One teenaged boy</td>
<td>None reported</td>
<td>Severe stomach pain for ~2 mo; endoscopic findings included severe inflammation, bleeding, and ulcerations in the duodenum</td>
<td>Several Redline energy drinks (250 mg of caffeine per 8-oz serving) per d</td>
<td>31</td>
</tr>
<tr>
<td>Marin Institute</td>
<td>One 14-y-old girl</td>
<td>Diabetes</td>
<td>2 d after drinking 1 can of SPIKE Shooter; she was hospitalized for a seizure</td>
<td>SPIKE Shooter</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>One 18-y-old girl</td>
<td>None reported</td>
<td>Died after sharing 4 cans of Red Bull with friends and then playing basketball</td>
<td>Red Bull</td>
<td>43</td>
</tr>
<tr>
<td>Source of Information</td>
<td>No. and of Age Patients</td>
<td>Previous Health Conditions</td>
<td>Symptoms</td>
<td>Reported Association With Energy Drink</td>
<td>Ref No.</td>
</tr>
<tr>
<td>----------------------</td>
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<td>---------------------------</td>
<td>----------</td>
<td>----------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Online news sources</td>
<td>One 14-y-old girl</td>
<td>Diabetes</td>
<td>Seizure</td>
<td>Reportedly drank 1 can of an energy drink before the seizure</td>
<td>25 and 38</td>
</tr>
<tr>
<td></td>
<td>One 17-y-old girl</td>
<td>None reported</td>
<td>Collapsed at the finish of a track race and was rushed to the emergency department after reporting chest pain and fatigue</td>
<td>Regularly skipped breakfast and drank 2 or 3 cans of Red Bull</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>One 29-y-old man</td>
<td>None reported</td>
<td>The man reportedly drank energy drinks and then engaged in the strenuous physical activity of motocross; he subsequently died from a cardiac arrest, presumably from coronary vasospasm caused by the energy drinks</td>
<td>Unknown energy drink; unspecified but large numbers of energy drinks that contained high levels of caffeine and taurine were consumed</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>One 47-y-old man</td>
<td>None reported</td>
<td>&quot;I thought I was having a heart attack. I thought I was going to die.&quot; The next day he reported feeling sore and exhausted from the experience</td>
<td>Two 8-oz cans of VPX Redline</td>
<td>118</td>
</tr>
</tbody>
</table>
Health Effects of Energy Drinks on Children, Adolescents, and Young Adults
Sara M. Seifert, Judith L. Schaechter, Eugene R. Hershorn and Steven E. Lipshultz

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An error occurred in the article by Seifert et al, titled “Health Effects of Energy Drinks on Children, Adolescents, and Young Adults.” published in the March 2011 issue of *Pediatrics* (2011;127(3):511–528; doi:10.1542/peds.2009-3592). On page 519, in Table 6, the table mistakenly used the “Number of case mentions” from the Poison Control Center (PCC) data as the denominator to calculate the percentages for the values in all of the other columns. The data that should have been used instead to calculate the percentages are the values under the column “Number of single exposures” of the PCC data. In addition, the column headings were modified to specifically state the column headings as shown in the PCC data. The revised table is provided here.

doi:10.1542/peds.2016-0454

**TABLE 6 Revised Table. American Association of Poison Control Centers’ Data on Caffeine Toxicity, 2006–2008.** All percentages have been recalculated with the corrected denominators using the number of calls involving single exposures.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Exposuresa</th>
<th>Age, y</th>
<th>Treated in Health Care Facility</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>≤5</td>
<td>6–19</td>
<td>&gt;19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6561</td>
<td>1208 (33.0)</td>
<td>1170 (32.0)</td>
</tr>
<tr>
<td>2008</td>
<td>3861</td>
<td>1208</td>
<td>1170 (32.0)</td>
<td>1090 (29.8)</td>
</tr>
<tr>
<td></td>
<td>4183</td>
<td>1176</td>
<td>1328 (31.7)</td>
<td>1404 (33.6)</td>
</tr>
<tr>
<td>2006</td>
<td>4350</td>
<td>1247</td>
<td>1427 (33.0)</td>
<td>1427 (33.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6561</td>
<td>1208 (33.0)</td>
<td>1170 (32.0)</td>
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<td>2008</td>
<td>3861</td>
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<tr>
<td>2006</td>
<td>4350</td>
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<td>1427 (33.0)</td>
<td>1427 (33.0)</td>
</tr>
</tbody>
</table>

*a Number of calls from single exposures.

*b Moderate outcomes are defined as more pronounced, prolonged, or systemic signs and symptoms requiring treatment but not life-threatening.

*c Major outcomes are defined as life-threatening signs or symptoms or marked residual disability.

*d Death as a direct result or complication of the poison exposure.
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An erratum has been published regarding this article. Please see the attached page for:
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