REVIEW ARTICLE

ARE ENERGY DRINKS PHYSIOLOGICAL?

Ahmed A. Alsunni

Department of Physiology, College of Medicine, University of Dammam, Saudi Arabia

Energy drinks are soft drinks promoted as boosting energy. They have become very popular all over the world since 1997. Energy drinks are fortified beverages with added dietary supplements. Like most of the soft drinks in the market these drinks are aggressively marketed but are not always transparent in providing ingredient information and quantities on their labels.[1] The promotion of natural ingredients in energy drinks to supply increased energy, increased alertness, and improved athletic performance leave a Physiologist wondering if these drinks deliver what they claim.

Energy drinks are designed to give an 'energy high' to the consumer by combination of stimulants and energy boosters. The main ingredients are stimulants, vitamins, and herbal supplements that the manufacturer has combined. The main ingredient in most energy drinks is caffeine. These drinks typically contain 80–150 mg of caffeine per 8 ounces, the equivalent of five ounces of coffee or two 12-ounce cans of caffeinated soft drink such as Mountain Dew, Coca Cola or Pepsi Cola.[2] Some contain high levels of sugar, and many brands offer artificially sweetened 'diet' versions.[3] In addition to methylxanthines (including caffeine) other commonly used ingredients are taurine, vitamin B, carbonated water, guarana, yerba mate, acai, various forms of ginseng, maltodextrin, inositol, carnitine, creatine, glucuronolactone, and ginkgo biloba. Other stimulants such as ginseng are often added to energy beverages and may enhance the effects of caffeine, and ingredients such as guarana themselves contain caffeine.[4]

In November of 2010, the University of Texas Medical School at Houston reported that energy drinks contain more caffeine than a strong cup of coffee, and that the caffeine combined with other ingredients (sometimes not reported correctly on labels) such as guarana, amino acid taurine, other herbs, vitamins and minerals may interact. Energy drinks consumed with alcohol may affect heart rates, blood pressure and even mental states. The caffeine content of energy drinks range from 70–200 mg per 16-oz serving whereas a 16-oz cup of coffee can contain 80–300 mg.[5]

Energy drinks are typically attractive to young people. Approximately 65% percent of its drinkers are between the ages of 13 and 35 years old, with males being approximately 65% of the market.[6] A 2008 statewide Patient Poll conducted by the Pennsylvania Medical Society's Institute for Good Medicine found that: 20% of respondents ages 21–30 had used energy drinks in high school or college to stay awake longer, to study or write a paper; 70% of respondents knew someone who had used an energy drink to stay awake longer to study or work.[7]

A study in the US carried out in 2007 found 51% of 496 college students surveyed drinking greater than one energy drink each month. Among college energy drink users, consuming energy drinks is particularly popular for insufficient sleep, when one needs more energy in general, to drink with alcohol while partying, and when studying for an exam or completing a major course project. This study reported that side effects of consuming energy drinks, including experiencing jolt and crash episodes, heart palpitations, and headaches occur in many energy drink users.[8]

Effects of Caffeine in humans

Although there is no human requirement for caffeine, yet, even low doses of caffeine (12.5 to 100 mg) improve cognitive performance and mood.[9] The literature pertaining to caffeine has reported a number of beneficial psychological and performance effects. Most of the studies are confounded by the use of 'above normal' doses of caffeine, however, the studies that have used realistic doses reported improved performance by reducing reaction times and improved attentional performance.[10–11] Improvement with caffeine can be best described as being seen across psychomotor and vigilance tasks, particularly when responses are sustained over time. Caffeine is also consistently associated with modulation of mood, most notably increasing alertness and reducing fatigue.[10]

However, caffeine has been found to have detrimental health consequences. Adverse effects associated with caffeine consumption in amounts greater than 400 mg include nervousness, irritability, sleeplessness, increased urination, arrhythmia, and stomach upset. Consumption also has been known to cause pupil dilation when taken with certain antidepressants or SSRIs.[12]

Acute caffeine consumption reduces insulin sensitivity[13] and increases mean arterial blood pressure.[14] High caffeine consumption is associated with chronic daily headaches, particularly among young women (age <40 years) and among those with chronic episodic headaches of recent onset.[15] Neural, cardiovascular, gastrointestinal, and renal dysfunctions have been associated with chronic caffeine ingestion.[16]

Caffeine has been shown to be an effective ergogenic agent by delaying fatigue and increasing time to exhaustion during endurance exercise.[17–20] Its efficacy

as an ergogenic aid during anaerobic exercise and strength/power events though is limited.[19, 21,22]

Benefits of Combination of Glucose & Caffeine

Psychological performance can be enhanced following the administration of a drink containing 25–50 g of glucose. Cognitive tasks affected include those assessing memory,[23,24] reaction times,[25] rapid visual information processing,[26,27] the Stroop paradigm,[26] Porteus maze and Block Design tasks,[27] the Brown-Peterson working memory task,[28] driving simulator performance,[29] kinaesthetic memory,[30] face recognition,[31] and serial subtraction mental arithmetic.[32–33]

Glucose preferentially affects tasks where the processing load is relatively high,[32–34] a proposal which is supported to some degree by the finding that glucose enhancement of memory was observed only when participants co-performed a secondary task.[24] Nevertheless, it is possible that the addition of a second psychopharmacologically active substance such as caffeine to a glucose drink may improve memory processes more successfully even under relatively non-demanding task conditions.[35]

Both glucose and caffeine can improve aspects of cognitive performance and, in the case of caffeine, mood. There are few studies investigating the effects of the two substances in combination. Some studies however suggest that there is some degree of synergy between the cognition-modulating effects of glucose and caffeine which merits further investigation.[35] Some researchers have assessed the cognitive and mood effects of an inferred glucose load from a meal in subjects who also consumed either caffeinated or decaffeinated coffee. Whilst these studies have tended to confirm an enhancement of cognitive performance and mood following caffeine,[36–39] the behavioural effects of a meal have been shown to vary with the time of day.

Seidl *et al.* examined the effects of capsules containing amounts of caffeine, taurine and glucoronolactone equivalent to one drink. They found that the decrements in P300 latency and reaction times, attention task performance and alertness associated with night time testing, were ameliorated in the active condition in comparison to an inert placebo.[40]

In addition to the behavioural modulation, both caffeine and glucose have peripheral effects. Along with hyperglycaemic effects, glucose ingestion is associated with heart rate acceleration.[32,41] On the other hand, the physiological effects of caffeine administration include heart rate deceleration,[42–44] although other authors have found no effects.[45–46] The effects on heart rate of caffeine and glucose in combination are not known.

Beneficial effects of energy drinks reported

A huge amount of caffeine in energy drinks provides the consumer the desirable effects of increased alertness, improved memory, and enhanced mood. However, caffeine can have harmful physical consequences as well.

The most commonly cited study in favour of energy drinks is the one conducted by Alford *et al*. They examined the effects of a most popular energy drink, which includes taurine, glucuronolactone, and caffeine amongst other ingredients. Assessments included psychomotor performance (reaction time, concentration, and memory), subjective alertness and physical endurance. They found that compared with control drinks, the studied Energy Drink significantly ($p<0.05$) improved aerobic endurance (maintaining 65–75% max. heart rate) and anaerobic performance (maintaining max. speed) on cycle ergometers. Significant improvements in mental performance included choice reaction time, concentration (number cancellation) and memory (immediate recall), which reflected increased subjective alertness.[47]

A number of studies have assessed the behavioural effects of 'energy drinks' containing both glucose and caffeine, along with other potentially active agents. Several studies have assessed the effects of a commercial drink containing caffeine, taurine, glucoronolactone, and vitamins amongst its ingredients. These studies have identified improvements in aerobic and anaerobic cycling performance,[47] performance of attentional and/or reaction time tasks,[47,48] afternoon driving performance[49] and various indices of alertness.[47–49]

Smit and Rogers compared the behavioral effects of two tailor-made energy drinks with a still water condition and a 'no-treatment' condition. Both energy drinks provided the same number of calories from glucose, and contained 75 mg caffeine. In comparison to water, no effects of the active treatments were found for either memory or rapid visual information processing, but simple reaction time and self-ratings of 'energetic-arousal' were significantly improved by both drinks.[50]

Smit and colleagues compared energy drinks to placebo and reported energizing effects among 18 to 55 year old participants, with effects being strongest 30 to 60 minutes after consumption and sustained for at least 90 minutes.[51]

Excess consumption of energy drinks may induce mild to moderate euphoria primarily caused by stimulant properties of caffeine and may also induce agitation, anxiety, irritability and insomnia.[47,52] During repeated cycling tests in young healthy adults an energy drink significantly increased upper body muscle endurance.[53] It has been suggested that reversal of

caffeine withdrawal is a major component of the effects of caffeine on mood and performance.[54]

A study reported a combination of caffeine and the sugar glucose in an energy drink to have restorative properties.[55] Some degree of synergy between the cognition-modulating effects of glucose and caffeine in energy drinks has also been suggested.[35] In one experiment, a glucose-based energy drink (containing caffeine, taurine and glucuronolactone) was given to eleven tired participants being tested in a driving simulator. Lane drifting and reaction times were measured for two hours post-treatment and showed significant improvement.[56]

A recent study that evaluated the effect of a commercially available energy drink on 'time to exhaustion' during treadmill exercise found that the particular energy drink tested significantly increased time to exhaustion during a moderate intensity endurance run and improved subjective feelings of focus, energy and fatigue.[57]

A recent aviation study examined the ability of a commercial energy drink containing caffeine to enhance acceleration tolerance and strength under G load. They found that a caffeine-based energy drink may enhance relaxed G tolerance and may increase strength, but does not impact acceleration tolerance duration.[58]

Another study investigated the acute effects of a glucose energy drink on cognitive functioning. The results indicated that compared with the placebo and no drink conditions, the energy drink decreased reaction times on the behavioural control task, increased subjective ratings of stimulation and decreased ratings of mental fatigue.[59]

Risks associated with Energy Drinks

Except caffeine, the effects of energy drink ingredients on physical and cognitive performances remain controversial. Some researchers identified moderate positive effects of energy drinks on performances, whereas others found results contrary to these. The adverse effects of energy drink can be related to either the toxicity of ingredients or specific situations in which energy drinks are used such as ingestion in combination with alcohol.

Caution is warranted even for healthy adults who choose to consume energy beverages. Consumption of a single energy beverage will not lead to excessive caffeine intake; however, consumption of two or more beverages in a single day, can.[12] The consumption of energy drinks may increase the risk for caffeine overdose and toxicity in children and teenagers.[60] Riesenhuber and colleagues found that caffeine in energy drinks promotes diuresis and natriuresis.[61]

Energy drinks do not provide electrolytes, and have a higher likelihood of an energy 'crash-and-burn' effect. Caffeine in energy drinks can excrete water from the body to dilute high concentrations of sugar entering the blood stream, leading to dehydration. If the body is dehydrated by 1%, performance is decreased by up to 10%.[62]

The risk of taurine toxicity after energy drink consumption remains low. However, whether the prolonged use of energy drinks providing more than 3g taurine daily remains to be examined in the future.[60]

In the US, energy drinks have been linked with reports of nausea, arrhythmia and emergency room visits.[63] The drinks may cause seizures due to the 'crash' following the energy high that occurs after consumption.[64]

The popular energy drink Red Bull was banned in France after the death of eighteen-year-old Irish athlete Ross Cooney, who died as a result of playing a basketball game after consuming four cans of the drink. This ban was challenged in the European Court of Justice in 2004. The French Scientific Committee concluded that 'Red Bull' has excessive amounts of caffeine. Denmark also banned 'Red Bull' for a while, although the ban has recently been revoked. Britain investigated the drink, but only issued a warning against its use by pregnant women and children.[65–66]

In 2009, a school in Hove, England requested that local shops do not sell energy drinks to students. This was a preventative measure, as all research shows that consuming high-energy drinks can have a detrimental impact on the ability of young people to concentrate in class.[67]

In many countries the practice of consuming great amounts of energy drink with alcohol is considered by many teenagers and students as a primary locus to socialize and to meet people. This pattern of energy drink consumption explains the enhanced risk of both caffeine and alcohol toxicity in youths.[60]

In recent years the consumption of alcohol mixed with energy drinks has become popular in young adults in North America. Studies have found that students who consume these are at increased risk for harms.[68–69] Research has established associations between energy drink use and heavier drinking and alcohol-related problems among college students. A study investigated the extent to which energy drink use might pose additional risk for alcohol dependence over and above that from known risk factors. This study reported that weekly or daily energy drink consumption is strongly associated with alcohol dependence.[70]

In a case report excessive intraoperative bleeding has been reported with chronic energy drink consumption.[71] Another case report has reported a 28-year-old man who was brought to the emergency room after sudden onset of tonic-clonic seizures and metabolic acidosis after drinking several cans of a caffeinated energy drink.[72] Vivekanandarajah *et al* have

reported case of a patient who presented with jaundice, abdominal pain, and markedly increased liver transaminases likely due to the increased consumption of an energy drink.[73]

Use of energy drinks in athletes

Energy drinks are very popular within athletes.[74–76] Using energy drinks before exercise has become a common practice among recreational and competitive athletes. Studies have shown that among American adolescents and young adults energy drinks are second only to multivitamins in popularity[74,77] with reports suggesting that 30% of this population group regularly consumes energy drinks.[78] Petroczi *et al*[76] reported that more than 40% of British athletes self-admitted to using energy drinks to improve their workouts or performance. Another study indicated that 89% of athletes competing in the Ironman World Triathlon Championships disclosed that they planned using caffeinated supplements prior to competition.[75] All types of athletes (endurance athletes to strength/power athletes) consume energy drinks. However, it appears that certain energy drinks are more popular with the endurance athletes due to reported benefits that caffeine, an ingredient common in energy drinks, has more effect on endurance performance but not on anaerobic performance.[17–22]

A recent American study that compared a famous brand of energy drink taken 1 hour before exercise with placebo for effect on repeated sprint performance in 15 women athletes. They reported that one serving of this energy drink provides no ergogenic benefit for women athletes engaging in sprint-based exercise.[79]

Need for this review

There is a wealth of studies demonstrating that the ingestion of either glucose or caffeine can benefit cognitive performance. The recent widespread growth in the use of 'energy drinks' containing both substances has not been matched by research directed at determining the behavioural effects of the substances in combination, despite claims by manufacturers that such drinks benefit mental function. Even less work has examined the potential cognitive effects of other substances present in such drinks at presumed sub-pharmacological levels. There is aggressive marketing of energy drinks mostly targeting young population. Companies are aggressively marketing it through advertisement, sponsorship of sports events and huge subsidies to outlets who sell them. Although energy drinks are targeted to young adult consumers, there has been no research regarding energy drink consumption patterns and effects. The high prices of famous brands were a barrier to popularity in the first decade, however over the last 5 years many cheap energy drinks, with no confirmed quality control system, have flooded the market.

The purpose of this review is this that Physiologists understand the urgent requirement to scrutinize these energy drinks and decide if these drinks and their use is Physiological or not. There is a need to determine their true effect and grade it as Physiological or otherwise. This should be followed by determining side effects and permissive amounts of different constituents by well designed Pharmacology and Physiology studies on animals and human volunteers. I predict that these studies will go a long way in permitting the use of these drinks in different scenarios particularly competitive sports.

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Address for Correspondence:

Dr. Ahmed A Alsunni, Department of Physiology, College of Medicine, PO Box 2114, University of Dammam, Kingdom of Saudi Arabia.
Email: ahmed8133@yahoo.ca