

Current perspectives of caffeinated energy drinks on exercise performance and safety assessment

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Abstract: Energy drinks and energy shots have become very popular among athletes and the general population. They typically contain carbohydrate, caffeine, and other nutrients purported to enhance mental and/or physical performance. Additionally, several caffeine-containing pre-workout supplements have been developed which are commonly consumed as a drink prior to and/or during exercise. While occasional ingestion of these types of products appears to be safe and may offer some ergogenic benefit, individuals who consume these products indiscriminately need to be careful and consider how ingestion of these products may affect the total daily intake of caffeine and other stimulants throughout the day, to minimize any adverse events and/or harmful side effects. This review provides an update as to the current literature on energy drinks and energy shots and provides practical recommendations for their appropriate use among athletes.

Keywords: energy drinks, energy shots, pre-workout supplements, exercise performance, cognitive function

Introduction

Energy drinks (EDs) are among the most common beverages consumed by adolescents and younger adult populations.^{1,2} They typically contain carbohydrate (ie, 10–15 g/100 mL or 10%–15% solution), electrolytes, and caffeine, along with nutrients purported to improve mental focus, attention, and/or alertness.² Most are considered as beverages and, therefore, have nutrient panels, while others are considered as dietary supplements and, therefore, have supplement fact labels. Most companies also offer a lower calorie version of energy EDs that are flavored with artificial sweeteners. On the other hand, energy shots (ESs) are typically 2–4 oz. servings of concentrated fluid containing nutrients purported to improve mental focus and alertness. Most are classified as dietary supplements. Because EDs and ESs contain carbohydrate, caffeine, and nutrients that may affect cognitive function, they are often consumed by individuals who are tired and need to stay awake for work or school, as well as athletes prior to, during, and/or following exercise as an ergogenic aid or recovery drink. The purpose of this review is to provide an update to a recent position stand from the International Society of Sports Nutrition regarding the scientific literature and make recommendations in regard to the role that ED and/or ES may have on exercise performance, energy expenditure/metabolism, and cognitive function.² Additionally, the safety considerations related to the use of ED and/or ES are discussed.

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Methods

A comprehensive review of the literature was made by searching the PubMed database of the US National Library of Medicine of the National Institutes of Health. The search strategy involved conducting a keyword search for EDs, ESs, commercial names of EDs and ESs, pre-workout supplements (PWSs), exercise, and performance. Additionally, a search was conducted for the primary nutrients found in EDs and ESs (eg, caffeine, taurine, glucuronolactone, citicoline, green tea, quercetin, and so on). A database of over 1,400 articles was considered for this review.

Nutritional recommendations for athletes

An ergogenic aid is any training technique, mechanical device, nutritional ingredient or practice, pharmacologic method, or psychological technique that can improve exercise performance capacity and/or enhance training adaptations.³ Since many activities require focus and attention to perform well, this also includes improvement of cognitive function. Since EDs and ESs, and PWSs contain nutrients that have been reported to improve physical and cognitive performance, they can serve as ergogenic aids for individuals needing to stay awake and alert, as well as for athletes.

Prior to discussing the ergogenic value of EDs and ESs, it is important to understand how nutrient timing affects exercise. Intense exercise uses carbohydrate as a primary fuel.^{3,4} The higher the intensity, the greater the contribution of carbohydrate to fuel exercise metabolism.⁵ However, the longer you exercise, the greater the contribution of fat as a metabolic fuel. Exercise training spares muscle glycogen utilization at a given exercise intensity, thereby allowing athletes to use fat to a greater degree as a metabolic fuel than carbohydrate at a given exercise intensity.⁵ Ingestion of carbohydrate can serve as an exogenous source of fuel during exercise with an oxidation rate generally between 30 and 60 g/hour, depending on the type of carbohydrate ingested.^{3,6} For this reason, many athletes ingest a blend of lower to moderate glycemic index carbohydrate prior to and during exercise via glucose electrolyte solutions and/or gels. Most athletes engaged in prolonged exercise for >1 hour, particularly in hot and humid environments, consume glucose electrolyte solutions (ie, sports drinks) in order to maintain carbohydrate availability and prevent dehydration.^{3,4}

In addition to carbohydrate, there are several nutrients that have been reported to affect exercise performance capacity and/or spare muscle glycogen utilization during exercise, thereby allowing athletes to exercise for a longer period of

time before fatigue.³ For example, caffeine has been reported to increase the release of free fatty acids during exercise and promote fat oxidation, thereby also sparing muscle glycogen utilization during exercise.⁷ Numerous studies have reported that caffeine ingestion prior to and/or during prolonged exercise enhances endurance exercise performance capacity.^{2,7-9} Additionally, acute ingestion of caffeine has been reported to enhance high-intensity intermittent exercise capacity.¹⁰⁻¹⁴ Therefore, there is rationale for athletes to use EDs and/or ESs prior to and/or during exercise simply as a convenient way to ingest caffeine.

EDs and ESs also typically contain nutrients purported to promote cognition and/or mental focus (eg, taurine, *Ginkgo biloba*, L-tyrosine, citicoline, 5-hydroxy-L-tryptophan, St John's Wort, and so on), stimulants (eg, caffeine, guarana, green tea, synephrine, yerba mate, yohimbine, tyramine, vinpocetine, and so on), and/or various purported ergogenic nutrients (eg, *Panax ginseng*, L-carnitine, D-ribose, β -alanine, inositol, citrulline, quercetin, and so on).² While not all of these nutrients have been reported to affect exercise and/or cognitive function^{3,15} and the amounts found in EDs and ESs are often lower than the effective doses reported in the literature,² the addition of these nutrients to EDs and ESs may provide some benefit for improving the cognitive function, particularly toward the end of an exercise training bout or competition. They may also provide benefit for individuals who are tired and/or need to maintain focus for work and/or study.

In terms of timing of nutrient intake around an exercise bout, it is recommended that athletes ingest a pre-exercise snack 30–60 minutes prior to exercise, containing 40–50 g of carbohydrate and 5–10 g of protein.^{3,16,17} Additionally, that athletes ingest caffeine prior to prolonged endurance exercise performance.^{3,7} Therefore, as long as consumption of the ED prior to exercise does not promote hypoglycemia, some EDs may serve as an effective pre-workout snack, particularly if they include carbohydrate, amino acids, and caffeine. During exercise lasting >1 hour, particularly in hot and humid environments, it is recommended that athletes consume about 0.75 L/hour of water depending on the sweat rate, or a glucose electrolyte solution (6%–8% solution).^{3,18,19} Consequently, some athletes use diluted EDs during prolonged exercise as a means of providing carbohydrate, caffeine, and electrolytes. Within 30–60 minutes after exercise, it is recommended that athletes ingest 0.5–1.0 g/kg body mass of carbohydrate to promote glycogen replenishment, as well as 0.25–0.5 g/kg body mass of protein.^{3,16-19} Thus, some athletes consume EDs after exercise along with some protein as a way to promote carbohydrate replenishment and recovery.

Effects on exercise performance

Energy drinks

Several studies have evaluated the effects of ingesting EDs, ESs, and/or PWSs on exercise performance. Much of the interest in use of EDs as an ergogenic aid was generated after Red Bull® (RB) was introduced into the market place. One serving of RB (about 250 mL) contains about 28 g of carbohydrate (11.3% solution) mostly from sucrose and glucose, taurine (1,000 mg), glucuronolactone (600 mg), sodium (100 mg), caffeine (80 mg), B vitamins (niacin [100%], vitamin B6 [250%], vitamin B12 [80%], and pantothenic acid [50%]) from ingredients that include carbonated water, citric acid, sodium bicarbonate, caffeine, niacinamide, calcium pantothenate, pyridoxine HCl, and vitamin B12. Thus, RB can serve as an effective source of carbohydrate and caffeine prior to exercise with some potential additive benefits from taurine and/or glucuronolactone on cognitive function.

There have been several studies that have evaluated the ergogenic value of RB on exercise performance. For example, Alford et al²⁰ investigated the effects consuming RB, a carbonated water beverage, or no beverage at all 30 minutes prior to performing an endurance exercise bout. Results revealed that endurance performance was increased by 8% and 14% following RB ingestion compared to the carbonated water and no beverage treatment, respectively. Similarly, Ivy et al⁸ evaluated the effects of trained cyclists consuming RB providing ~2.3 mg/kg body mass of caffeine or a flavored placebo 40 minutes prior to performing a 1-hour time trial at 70% of maximal power output. Results revealed that participants ingesting RB completed the time trial ~4.7% faster than placebo treatment.⁸ Moreover, Rahnama et al²¹ investigated the effects of ingesting of RB or Hype® (containing 24.8 g carbohydrate, 75 mg caffeine, 1 g taurine, and 600 mg glucuronolactone) 40 minutes prior to performing a maximal exercise capacity test compared to a placebo containing water and citrus substances. Results revealed that ED consumption increased maximal aerobic capacity and time to exhaustion, with no differences observed in heart rate or lactate responses. These findings suggest that ingestion of RB prior to exercise can enhance endurance exercise performance and/or maximal exercise capacity.

Some studies also indicate ingestion of EDs before resistance exercise can affect exercise capacity. For example, Forbes et al²² gave 15 physically active college-aged students RB (standardized with 2 mg/kg body mass of caffeine) or a placebo 60 minutes prior to exercise. The researchers reported that RB significantly increased total bench press repetitions over three sets by 6%, with no effect on cycling

anaerobic sprint peak or average power. Del Coso et al²³ evaluated the effects of RB ingestion containing 1 or 3 mg/kg body mass of caffeine or a placebo 60 minutes prior to performing bench press and squat resistance exercise. Results revealed that ingestion of the ED with 3 mg/kg body mass of caffeine increased maximal power output by 7% in both half squat and bench press, as compared to the ingestion of a placebo. However, the lower caffeine dose had no effect on performance. Gonzalez et al²⁴ reported that ingestion of RB 10 minutes prior to exercise increased the number of repetitions performed during four sets of the squat or bench press exercise using 80% of the subject's one repetition maximum by 11.9%. In addition, the average power output for the workout was significantly higher for subjects consuming RB.

However, not all studies found significant effects. For example, Candow et al²⁵ reported ingestion of 2 mg/kg body mass of sugar-free RB 1 hour prior to exercise had no effects on run time to exhaustion performed at 80% of peak oxygen uptake. Likewise, Astorino et al²⁶ reported that RB ingestion 60 minutes prior to repeated agility tests in female soccer players had no significant effects on performance. Nevertheless, majority of the studies indicate that RB ingestion prior to exercise can influence exercise performance capacity.

Energy shots

A couple of studies have evaluated the effects of ES ingestion on exercise performance. For example, Schubert et al²⁷ evaluated the effects of consuming an ES on 5 km time trial performance in trained runners. Participants ingested a placebo (2 oz. of Dragonfruit Vitamin Water™ with no caffeine), Guayaki Yerba Mate™ Organic ES containing 80 mg of caffeine, or RB Energy Shot™ containing 80 mg caffeine in a randomized, counterbalanced, and crossover manner prior to performing a 5 km time trial on a treadmill. The researchers found that time trial performance was not affected by ES ingestion. Conversely, Seifert and Connor²⁸ evaluated the effects of consuming Body Glove Surge® (18 g carbohydrates, 3 g protein, and 150 mg caffeine per serving), 5-Hour Energy® (~205 mg caffeine, ~480 mg taurine, 30 mg niacin), or a non-caloric placebo on time trial performance following cycling for 120 minutes at 70% of peak oxygen uptake with intermittent 2-minute intervals at 90% of peak oxygen uptake. Participants ingested a half dose of the ESs at 30, 60, and 90 minutes of exercise, with 75 mL of water. Participants then performed a 6-minute time trial. Results revealed that ingestion of the ES containing carbohydrate, protein, and caffeine significantly improved cycling power output and auditory response time following 2 hours of moderate and

high-intensity interval cycling compared to RB and placebo ingestion. Marczinski et al²⁹ reported that ingestion of an ES (5-Hour Energy) did not affect reaction times or inhibition failures while performing behavioral control tasks (the cued go/no-go task) in comparison to consuming a cranberry juice placebo or no drink. Similarly, Monaghan et al³⁰ reported that ES ingestion (5-Hour Energy Extra Strength Berry Flavor) 30 minutes prior to law enforcement officers participating in target shooting impaired pistol steadiness in comparison to ingesting a flavored water placebo, suggesting an ergolytic effect on fine motor skill. Although more research is needed, these findings suggest that ES ingestion has less consistent effects on exercise and/or motor skill performance than ED consumption.

PWSs

PWSs have also become a popular pre-workout beverage. They are typically available in a powder form that is added to water and consumed as an energy drink prior to exercise. Some companies also offer a ready-to-drink (RTD) version of their PWSs. These products generally have a small amount of carbohydrate, caffeine, and nutrients purported to improve acute exercise capacity. Some also include nutrients that can help training adaptations. For example, Walsh et al³¹ evaluated the effects of ingesting a sugar-free ED containing ~2 g of caffeine, taurine, and glucuronolactone with amino acids (L-leucine, L-isoleucine, L-valine, L-arginine, and L-glutamine) 10 minutes prior to performing a run to exhaustion test at 70% of peak oxygen uptake.³¹ The researchers reported that participants ingesting the PWS were able to run 12.5% longer than during placebo treatment (flavored and colored water).³¹ Hoffman et al³² evaluated the effects of ingesting a PWS containing branched chain amino acids (BCAAs), creatine, taurine, caffeine, and glucuronolactone on resistance training performance (six sets of 10 repetitions at 75% of one repetition maximum). Results revealed that performance was enhanced during set 5 of the exercise bout, and the total number of repetitions and the lifting volume only tended to be greater. However, growth hormone and insulin levels were higher following PWS ingestion compared to a maltodextrin placebo. Smith et al³³ reported that ingestion of a PWS drink containing 18 g of whey protein, *Cordyceps sinensis*, creatine, citrulline, ginseng, and caffeine 30 minutes prior to exercise during 3 weeks of high-intensity interval training significantly increased peak oxygen uptake, critical velocity, fat-free mass, and training volume in comparison to an isocaloric flavored placebo containing maltodextrin.

Furthermore, Jagim et al³⁴ evaluated the effects of ingesting a multi-ingredient PWS (4 g carbohydrate, 130 mg sodium, 2 g creatine hydrochloride, 2 g beta-alanine, 1.5 g betaine, 1 g taurine, 600 mg *N*-acetyl L-cysteine, 300 mg alpha-glycerol phosphoryl choline, 6 g citrulline malate, 500 mg beta vulgaris [beet root extract], 3 g L-leucine, 1.5 g L-isoleucine, 1.5 g valine, 1.5 g L-tyrosine, 300 mg caffeine anhydrous, 50 mcg huperzine A, and 5 mg *Piper nigrum* fruit extract) 30 minutes prior to performing a counter movement vertical jump test, five sets of five repetitions at 85% of 5 repetition maximum on the back squat and bench press, followed by a single set to failure, and an anaerobic capacity sprint test. Results revealed that the number of repetitions during the bench press, as well as anaerobic sprint capacity, were increased to a greater degree following PWS ingestion in comparison to a flavor and color match water placebo. Similarly, Martinez et al³⁵ reported that ingestion of a PWS containing carbohydrate, β -alanine, creatine nitrate, L-tyrosine, ribose, amino acids, and caffeine and other nutrients significantly improved anaerobic peak and mean power in comparison to ingesting a color- and flavor-matched maltodextrin placebo. Jung et al³⁶ evaluated the effects of ingesting a PWS containing beta-alanine (3 g), creatine nitrate (2 g), arginine alpha-ketoglutarate (2 g), *N*-acetyl-L-tyrosine (300 mg), and caffeine (284 mg) with and without 20 mg of synephrine on resting energy expenditure and acute exercise performance. The researchers reported that PWS ingestion prior to exercise increased resting energy expenditure but had limited effects on muscular endurance and anaerobic sprint capacity in comparison to ingesting a color- and flavor-matched maltodextrin placebo. Further, adding synephrine did not provide additive benefits.

Collins et al³⁷ investigated the effects of ingesting a placebo beverage or an RTD PWS containing caffeine (200 mg), beta-alanine (2.1 g), and arginine nitrate (1.3 g) for 7 days on exercise performance. The researchers found that acute PWS ingestion-maintained recovery leg press strength to a greater degree, increased leg press repetitions to failure, and increased bench press and total lifting volume in comparison to a flavor- and color-matched dextrose placebo. However, 4 km cycling time trial performance was not affected by acute PWS ingestion. Finally, Cameron et al³⁸ evaluated the effects of ingesting multi-ingredient PWS containing caffeine, β -alanine, beet root extract along with some nutrients purported to enhance cognitive function on the resting metabolism and exercise performance in recreationally active females. Results revealed that PWS ingestion increased the

resting metabolism and improved upper body muscular endurance and anaerobic capacity in comparison to a flavor- and color-matched placebo. Collectively, these findings and others provide evidence that ingesting PWSs prior to exercise can affect acute exercise capacity.

Effects on cognitive performance

Energy drinks

A number of studies have also assessed the effects of consuming EDs on cognitive performance. For example, Seidl et al³⁹ evaluated the effects of ingesting RB on mood and motor function in fatigued participants. The researchers found that reaction time was significantly longer in the placebo group (wheat bran with water) but remained unchanged in the ED group. Additionally, vitality scores, feelings of well-being, and social extroversions were significantly decreased in the placebo group, while they remained unchanged in the ED group.³⁹ In a similar study, Howard and Marczynski⁴⁰ reported that consuming 1.8, 3.6, or 5.4 mL/kg of RB decreased reaction times on the behavioral control task, increased subjective ratings of stimulation, and decreased ratings of mental fatigue, compared to a placebo beverage and non-drink treatment. The greatest improvements were observed with the lower dose and improvements diminished as the dose increased.

Mets et al⁴¹ evaluated the effects of consuming RB or a placebo drink (RB drink containing no taurine, caffeine, or glucuronolactone) after 2 hours of simulated driving before driving for an additional 2 or 4 hours of uninterrupted driving. Results revealed that RB consumption significantly improved driving relative to placebo, including improving SD of lateral position, fourth hour of driving, the SD of speed, subjective driving quality, and mental effort to perform the test during the third hour of driving. The researchers also found that RB ingestion decreased subjective sleepiness during the third and fourth hour of driving and uninterrupted driving. Moreover, Wesnes et al⁴² evaluated the effects of sugar and non-sugar containing RB on cognitive function and mood compared to a carbonated water and RB-flavored placebo in healthy young volunteers. Results revealed that both versions of RB significantly improved memory and speed of correct responses on memory and recognition tests. Rao et al⁴³ reported that ingesting an ED containing 40 mg of caffeine and 60 g of glucose enhanced the measures of electroencephalogram brain activity in comparison to a color- and taste-matched placebo. The authors concluded that improved brain activity could translate to improvements in reaction time.

Scholey and Kennedy⁴⁴ investigated the effects of ingesting 1) a color- and flavor-matched ED placebo beverage; 2) ED containing caffeine (75 mg); 3) ED containing glucose (37.5 g); 4) ED containing ginseng (12.5 mg) and *G. biloba* (2.0 mg); or 5) ED containing all of these nutrients 30 minutes prior to performing cognitive performance and mood assessments. The researchers reported that secondary memory and speed of attention were significantly improved with ED ingestion compared to a placebo beverage.⁴⁴ Smit et al⁴⁵ conducted three studies to assess the effects of EDs containing carbohydrate, caffeine, and taurine with and without carbonation on motor task performance, mood, and side effects. Results revealed that caffeine was most likely the primary ingredient that improved mood and performance during fatiguing and cognitively demanding tasks, with carbohydrates playing a minor role. Collectively, these reports provide some support that ingestion of EDs prior to exercise can affect cognitive performance.

Energy shots

Only one published paper was found that reported the effects of ingesting an ES on cognitive performance. In this study, Marczynski et al²⁹ assessed the effects of acute ingestion of a popular ES (5-Hour Energy) on subjective and objective psychological measures for 6 hours following consumption. Participants ingested the ES, a cranberry juice placebo, or no drink while completing Profile of Mood States ratings hourly for 6 hours. Results revealed that ES ingestion did not significantly affect subjective ratings of vigor and fatigue, although vigor values were maintained to a greater degree and fatigue values were consistently lower with ES ingestion.

Pre-workout supplements

Hoffman et al⁴⁶ found that when male strength/power athletes consumed 120 mL of a commercially available ED (Redline Extreme® containing caffeine anhydrous, beta-alanine, vitamin C, and the following herbal and botanical compounds: evodiamine, *N*-acetyl-L-tyrosine, hordenine, 5-hydroxytryptophan, potassium citrate, *N*-methyl tyramine, sulbutiamine, vinpocetine, yohimbine HCl, and St John's wort extract) or a color- and flavor-matched placebo, reaction time and subjective feelings of energy and focus were significantly improved in those consuming the ED. Walsh et al³¹ reported that PWS consumption 10 minutes prior to exercise promoted perceptions of greater focus, energy, and less fatigue prior to exercise and improved the ratings of focus and energy 10 minutes into exercise. However, perceptions of energy, fatigue, and focus were not affected following exercise.³¹

Jagim et al³⁴ found that PWS ingestion 30 minutes prior to resistance exercise improved subjective ratings of fatigue and alertness. Likewise, Jung et al³⁶ reported that ingestion of a PWS containing beta-alanine, creatine nitrate, arginine alpha-ketoglutarate, *N*-acetyl-L-tyrosine, and caffeine prior to exercise improved the perceptions about readiness to perform and cognitive function. Finally, Cameron et al³⁸ reported that ingestion of a multi-ingredient PWS improved the feelings of focus following high-intensity exercise in recreationally active females. Collectively, these findings suggest that consumption of PWSs can affect cognitive performance and/or psychological perceptions related to exercise.

Frequent use of EDs, shots, and PWSs

A number of studies have evaluated the effects of daily ingestion of one to two servings a day of RTDs or PWSs for up to 10 weeks on training adaptations and markers of safety in healthy individuals. These studies provide insight as to the impact of frequent ED and PWS on performance and markers of health. For example, Smith et al³³ evaluated the effects of ingesting a PWS containing caffeine (100 mg), creatine (1.5 g), BCAA (1 g), whey protein (9 g), *C. sinensis* (2.5 g), citrulline (0.75 g), and Rhodiola taken 30 minutes prior to high-intensity interval training for 3 weeks. The researchers found that PWS consumption significantly increased peak oxygen uptake, critical velocity, and gains in fat-free mass. Ormsbee et al⁴⁷ evaluated the effects of consuming one serving of whey protein, casein protein, BCAA, creatine, beta alanine, and caffeine (NO-Shotgun®) before each resistance training workout and one serving of whey protein, casein protein, BCAA, creatine, and beta alanine (NO-Synthesize®) immediately after each workout and on non-resistance training days for 6 weeks on training adaptations. The researchers reported that pre- and post-exercise supplementation of these supplements promoted greater gains in fat-free mass and improvements in anaerobic capacity. Kedia et al⁴⁸ evaluated the effects of ingesting a PWS containing creatine, betaine, and *Dendrobium* extract on training adaptations during 6 weeks of resistance training. Participants taking the PWS reported significantly greater subjective ratings of energy and concentration and less fatigue. However, PWS ingestion did not affect changes in body compensation or performance.

Collins et al³⁷ reported that 5 days of ingestion of an RTD PWS containing caffeine (200 mg), beta-alanine (2.1 g), and arginine nitrate (1.3 g) prior to exercise maintained recovery leg press strength, endurance, and lifting volume to a greater degree than ingesting a placebo. However, 4 km cycling time trial performance was not affected by short-term

PWS ingestion. Jung et al¹¹ evaluated the effects of daily consumption of two doses of a popular PWS with and without *p*-synephrine for 8 weeks on training adaptations in resistance-trained athletes. Results revealed evidence that 4 weeks of PWS and PWS with *p*-synephrine improved some indices of cognitive function and exercise performance during resistance training in apparently healthy males. However, these effects were similar to placebo ingestion after 8 weeks of supplementation, suggesting that the ergogenic benefits may fade over time.

Arent et al⁴⁹ evaluated the effects of consuming a multi-ingredient PWS containing raspberry ketone, capsaicin, caffeine, garlic, and *Citrus aurantium* for 8 weeks on weight loss in overweight adults participating in an exercise and diet program. Results revealed that men taking the PWS experienced greater gains in fat-free mass, while women experienced greater loss in hip circumference. Additionally, PWS ingestion promoted greater reduction in leptin and increases in adiponectin, suggesting an impact on appetite hormones. No adverse effects were reported. Finally, Lockwood et al⁵⁰ evaluated the effects of consuming an ED containing 1.8 g of a proprietary blend containing taurine, caffeine, green tea extract, glucuronolactone, and ginger extract with vitamins and minerals daily for 10 weeks with and without exercise on body composition, exercise capacity, and markers of health. The researchers reported that daily pre-workout ED consumption without exercise had no effects on body composition, cardiorespiratory fitness, or strength in sedentary males. However, when combined with exercise, pre-exercise and daily ED consumption improved some physiological adaptations to endurance and resistance training. Collectively, these findings suggest that daily ingestion of ED and/or PWSs may appear to enhance training adaptations.

Safety considerations

The clear majority of studies that have evaluated the acute ingestion of ED, ES, or PWS on exercise and/or cognitive performance have shown they are well tolerated in healthy individuals. Additionally, the studies described above reported that daily and pre-exercise consumption of EDs or PWSs for up to 10 weeks during training was well tolerated and not associated with any serious adverse effects.^{11,33,37,47–56} Nevertheless, a few studies have reported that acute ingestion of ES, ED, and/or PWS caused a short-term increase in resting systolic and/or diastolic blood pressure generally in the 2–5 mmHg range.^{29,57,58} However, the reported changes were typically less than observed from standing up or light walking, and most studies have found that acute^{36,50,58,59}

and longer-term ingestion of ED, ES, or PWS^{11,47,49–56} had no effects on resting or exercise blood pressure. Moreover, Collins et al³⁷ reported that PWS ingestion had no effects on hemodynamic responses to a postural challenge and Molnar and Somberg⁶⁰ reported improved endothelial function after ingestion of some EDs, which could provide health benefit.⁶⁰ Nevertheless, it would be prudent for individuals with hypertension to exercise caution when consuming ED, ES, and/or PWS, as they may cause a small transient increase in systolic blood pressure.

Concerns have been raised about the indiscriminant use of EDs and ESs.^{61–64} This includes concern about the use of EDs to counteract the depressive effects of alcohol, which, may lead to excessive alcohol intake and/or intoxication.^{59,65–69} For example, several studies suggest that individuals who mix alcohol with EDs are more likely to consume more alcohol and/or engage in risky behaviors.^{70–81} While discussing the effects of concomitant use of EDs with alcohol goes beyond the scope of this paper, it is clear that consumption of EDs with alcohol may increase the likelihood of intoxication and risky behavior, and should therefore be discouraged. For more information on this topic, the reader is referred to a comment published by the American Medical Association related to the safety concerns of mixing ED with alcohol.⁸²

Concerns have also been raised that the indiscriminate use of EDs and/or ESs may lead to excessive caffeine intake and negative health outcomes.^{83–88} It should be noted that the amount of caffeine found in most standard size EDs and ESs (ie, about 80–200 mg) is less than that found in a premium cup of coffee depending on the size (eg, 180–475 mg) and some soft drinks; yet, these types of concerns have generally not been raised about the use of these products. Nevertheless, if individuals do not carefully monitor their caffeine intake, it is possible to unknowingly ingest high levels of caffeine. For example, if an individual had a premium cup of coffee, several high caffeine-containing soft drinks, and several EDs, ESs, and/or PWSs per day, he/she could have easily consumed 1,000–2,000 mg of caffeine or more per day, particularly if the amount of caffeine contained in these products is not clearly labeled.

According to the Council for Responsible Nutrition,⁸⁹ by law, manufacturers are permitted to label and market liquids or as a dietary supplement if it is intended to supplement the diet. ED marketed as beverages will have a “Nutrition Facts” panel, while those marketed as a dietary supplement will have a Supplement Facts panel. The US Food and Drug Administration issued guidance to industry suggesting that products should clearly label serving sizes and ingredient

content (including caffeine), and that products packaged in containers larger than 8 oz. should be labeled as a beverage. The Code of Federal Regulations in the USA limits the amount of caffeine that can be added to soft drinks to 0.02% by volume or about 70 mg caffeine per 12 oz., as this is considered by the US Food and Drug Administration as generally recognized as safe.⁸⁹ The Nutrition Facts Panel on food labels is not required to always list caffeine since it is not a nutrient.² However, if caffeine is added to a food, it must then be listed.⁸⁹ For this reason, it is possible for individuals to unknowingly consume more caffeine in the diet than they realize, particularly if it comes from food or beverages that do not describe the total caffeine intake from all sources.^{83,84,86,87}

The potential side effects of caffeine include insomnia, nervousness, restlessness, gastric irritation, nausea, vomiting, tachycardia, tremors, and anxiety, with doses as low as 250–300 mg.^{82,86,90,91} While caffeine is naturally found in high amounts in the food supply and is considered generally recognized as safe as noted above when consumed in moderation,⁹² any substance could be toxic at high-enough doses or pose a health risk to some medical populations and/or in individuals who are genetically more sensitive to caffeine. Nawrot et al⁹³ reported ingestion of up to 400 mg of caffeine (6 mg/kg) was not associated with any adverse effects in adults, and Higdon and Frei⁹⁴ suggested that children can typically tolerate doses <3 mg/kg per dose without untoward side effects. However, one must also consider whether there are any other stimulants in the ED, ES, or PWS, as there may be additive and/or synergistic effects.²

Thus, it is advisable to consider consuming only the EDs, ESs, and PWSs that have been assessed for acute and longer-term safety as described in the studies above. Finally, since some EDs contain relatively large amounts of sugar, it is advisable that individuals with diabetes mellitus or pre-diabetes mellitus should avoid excessive consumption of high glycemic EDs or PWSs. Therefore, it would be prudent for individuals with uncontrolled hypertension, arrhythmias, diabetes mellitus, peripheral artery disease, and/or cardiovascular disease to avoid use of EDs, ESs, and/or PWSs with known cardiostimulant effects.² While the available evidence to date suggests that use of EDs, ESs, and/or PWSs is generally well tolerated and safe in healthy populations when used as intended and is similar to ingesting other foods and beverages containing caffeine, care should be taken to consider all sources of caffeine and stimulants in the diet from food, beverages, and dietary supplements, so that individuals do not unknowingly consume excess caffeine in their diet.

Conclusion

EDs, shots, and PWSs are popular beverages in the society today. Most contain carbohydrate, caffeine, and other nutrients purported to improve exercise and/or cognitive performance. The preponderance of scientific evidence to date suggests that consumption of these products prior to exercise can improve anaerobic and endurance exercise capacity and/or cognitive performance without untoward side effects.² However, the amount of caffeine and other stimulants contained in EDs, ESs, and PWSs needs to be considered as part of the total daily intake from food and beverages, so that individuals do not unknowingly consume excessive amounts of sugar and/or caffeine. Additionally, it is prudent for individuals with uncontrolled hypertension, arrhythmias, diabetes mellitus, peripheral artery disease, and/or cardiovascular disease to avoid use of EDs, ESs, and/or PWSs with known cardiostimulant effects. Additional research should evaluate the acute and chronic safety and efficacy of ingesting EDs, ESs, and PWSs on health and performance.

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