Journal of Food and Nutrition Research, 2020, Vol. 8, No. 1, 33-38
Available online at http://pubs.sciepub.com/jfnr/8/1/5
Published by Science and Education Publishing
DOI:10.12691/jfnr-8-1-5

Energy Drink Mechanisms of Harm in Young People and Adolescents: A Narrative Review

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Received January 11, 2019; Revised April 04, 2019; Accepted January 20, 2020

Abstract Caffeinated energy drink (ED) consumption has grown rapidly worldwide, particularly among young people. This review considers whether the health outcomes associated with young people's energy drink consumption are too narrowly focused on physiological mechanisms, and whether there is evidence to support the hypothesis that energy drink consumption incurs broader social costs. A narrative review of studies published between 1997 and 2017 was undertaken. The focus was the behavioural, physical and mental health outcomes associated with sugar (including glucose, sucrose and fructose) and caffeine, the two main ingredients of EDs. Possible causal mechanisms linking ingredient to outcome are discussed. The population of interest was children and adolescents aged 6 to 18 years of age. A total of 33 studies were identified. ED consumption was found to be associated with health problems including high blood pressure, cardiovascular disease, headaches, sleep disorder, substance use, stress and hyperactivity however causal relationships could not be determined for all outcomes. The caffeine and sugar contained in EDs can promote adverse effects on children and adolescents. There is a weak evidence that these effects could extend beyond physical health to educational attainment, mental health and substance use. Increased awareness and further prospective studies are required.

Keywords: *energy drinks, children, adolescents, caffeine, health outcomes*

Cite This Article: Manal Alhumud, Simon Moore, and Kelly Morgan, "Energy Drink Mechanisms of Harm in Young People and Adolescents: A Narrative Review." *Journal of Food and Nutrition Research*, vol. 8, no. 1 (2020): 33-38. doi: 10.12691/jfnr-8-1-5.

1. Introduction

An energy drink (ED) is a non-alcoholic beverage that primarily contains caffeine and sweeteners, served in combination with brand specific-ingredients that can include herbal extracts [1,2]. There is growing interest in the health consequences of ED consumption among young people, partly due to the growth in sales of EDs to this demographic [3,4]. The well-publicised health outcomes of EDs, however, are mostly limited to the immediate physiological effects such as increased heart rate, heart rhythm irregularities, and high blood pressure. The literature concerning health outcomes for EDs' active ingredients, sugar and caffeine, is far broader and, as is argued here, suggests ED consumption may have more far ranging effects on a young person's health and impose additional social costs than is currently being captured.

Over the past two decades, the popularity of EDs has rapidly worldwide grown, particularly among young people. By 2006 there were more than 500 brands globally [5] with reported consumption at more than 5.8 billion litres across 160 countries [6]. EDs differ from traditional sports drinks by containing more caffeine and fewer carbohydrates [7]. EDs were originally targeted at athletes but as the ED market grew manufacturers broadened their marketing efforts to include young people aged between 16 and 35 years, the result of which was a 155% increase in sales between 2006 and 2014 among this group [8,9]. In Europe, the highest ED consumption rates are now found among young people aged between 10 and 18 years [10].

Caffeine and sugar are the main active ingredients in EDs [2]. A single serving of eight to 12 fluid ounces (fl. oz.) can contain between 72mg and 150mg of caffeine and 25g to 33g of sugar [1,2]. Many brands contain two to three servings in one beverage can, which raises the caffeine content to as high as 294mg per can [11]. In comparison, a double espresso coffee contains around 80mgof caffeine andpopular carbonated sugar sweetened beverages (SSBs) cancontain 10.6g of sugar per 100ml (35g of sugar per 11 fl. oz. can) [12,13,14]. Other ingredients in EDs can include guarana, kola nut, yerba mate and cocoa, which also contribute caffeine to the beverage [6-11]. Current guidelines indicate that healthy adults should not consume more than 400 mg of caffeine

daily and adolescents are advised to limit their daily consumption of caffeine to 100 mg daily, less than a single serving of some EDs [15,16]. According to the World Health Organization (WHO) 2015 dietary guidelines, individuals should limit their sugar intake to less than 10% of their overall daily calorie intake, equating to 44g of sugar for children. Some 17 fl. oz. servings of ED exceed this limit, containing 55 g sugar [17].

2. Energy Drink Determinants of Health

Documented associations between the two active ingredients of EDs, sugar and caffeine, and young people's health and behaviour are summarised in Figure 1.

2.1. Sugar

SSB consumption is positively associated with weight gain and obesity in both children and adolescents [18]. The extent of SSB consumption measured at age nine years has been shown to predict increases in body mass index (BMI) across the following three years [19]. A study that compared children with a preference for high-sugar foods to peers who preferred low-sugar foods, found significantly higher levels of plasma leptin concentrations in the high-sugar preference group [20]. This finding is important as higher levels of leptin are associated with obesity while leptin resistance can lead to an inability to control hunger and can therefore lead to greater food consumption [21]. There is strong evidence demonstrating that SSB intake is associated with increased waist circumference [22,23,24], higher BMI [25,27], higher body fat percentages [26] and obesity [28,29].The relationship between SSB consumption and blood pressure however is less clear. While some studies have documented associations between SSB intake and increased diastolic blood pressure only [30], others have noted positive associations only between SSB consumption and increased systolic blood pressure [22-31]. On the other hand, the literature widely documents that sleep disorders, substance use and mental health outcomes such as distress and hyperactivity, are positively associated with greater SSB consumption [32,33,34]. Previous research has shown that a positive association between SSB consumption and an increased risk of asthma in children [35]. SSB consumption is further associated with changes in the insulin resistance index and higher values of β-cell function [36,37,38]. Insulin resistance occurs when parts of the body such as muscle, fat, and liver cells do not adequately respond to the hormone insulin and, as a result, the body is less able to absorb glucose from the bloodstream [37]. Consequently, insulin resistance in children and adolescents has been positively associated with a number of health conditions including cardiovascular disease, hypertension, endothelial dysfunction and diabetes [37]. Premenarcheal girls who reported consumption of one and a half servings of sweetened beverages per day were, on average, 24% more likely to exhibit menarche in the following month compared to girls consuming fewer than two servings of sweetened drinks weekly [38]. Studies examining consumption and oral health have noted tooth enamel demineralisation resulting from the low pH of SSBs, causing enamel loss [39]. Up to 57% of children aged 11 to 14 years exhibit enamel demineralisation that is attributable to their sugar consumption in the UK, for example [39]. One serving of an ED (8. oz) contains similar levels of sugar content to that of popular sugar sweetened beverages such as cola [2]. It is therefore likely that the risks to health and associated health behaviours from EDs should be expanded to include obesity, high blood pressure, sleep disorder, substance use, mental health outcomes, asthma, cardiovascular disease, early menarche and tooth erosion.

Figure 1. The effects of over dosses energy drinks on young people, based on the two active ingredients sugar and caffeine

2.2. Caffeine

The consumption of caffeine has been shown to be associated with depression, anxiety, stress, and lower academic achievement and sleep deprivation among adolescents [40,41]. In addition, evidence suggests that caffeine consumption is positively associated with depression, stress, suicidal ideation and sleep dissatisfaction in young people [42]. The nature of the association between caffeine and circadian dysregulation among young people suggests EDs may cause sleeping difficulties, excessive tiredness and shorter sleep durations (≤8.5 hours) [43,44], when compared to young people who do not consume caffeine. Poor sleep quality is further associated with risk taking, with studies demonstrating greater risk of alcohol use, tobacco use, and aggression among students who sleep less than eight hours a day [45,46]. Furthermore, due to the negative effects of poor sleep on mental health, sleep quality and sleep duration has been shown to be positively associated with diabetes, cardiovascular disease, obesity and depression [47]. Those who experience a sleep disorder are also at greater risk of hypertension, stroke, coronary heart disease and cardiac arrhythmias compared to those who sleep eight or more hours a night [47,48]. Caffeinated drink consumption has also been associated with reports of physical complaints such as headaches, stomach-aches, poor appetite and irritation [1,2]. An increase of such complaints has been observed in children aged 10 to 13 years with a higher prevalence in those consuming EDs compared to those consuming SSBs [49]. Excessive caffeine consumption of over 200mg per day is positively associated with hypertension [49] and high systolic and diastolic blood pressure is observed immediately following consumption [50,51].

3. Mechanisms

While evaluating the effects of sugar and caffeine on physical, mental and behavioural outcomes is important, it is also necessary to consider whether there are feasible causal mechanisms underpinning a documented relationship.

It has been established that a diet high in sugar is associated with physical health, primarily weight gain due to excessive calorie intake [52]. EDs are high in sugar and therefore are likely to cause weight gain, their consumption does not lead to satiety unlike similarly calorific solid foods [53]. Being overweight or obese is, in turn, an established risk for diseases that include diabetes, cardiovascular diseases, and fatty liver disease [54,55]. Furthermore, high sugar intake is associated with diabetes and is known to contribute to mental health problems such as depression, stress, anxiety, and sleep disorder; sleep deprivation can also increase the risk of stress [53] but stress can also lead to weight gain because overeating is a known coping mechanism [56]. However, uncertainty remains on the actual relationship between sugar intake, stress and sleep [57].

The consumption of caffeine is associated with high blood pressure, a known risk factor for tachycardia and cardiovascular disease[2]. While it is established that caffeine is generally a stimulant, how this effect manifests is shown to vary by dose: 250mg of caffeine consumption has been shown to cause elation, 500mg of consumption has been shown to lead to irritability[58]. Caffeine has been associated with a number of mental health problems including stress, depression, and anxiety, along with a plethora of health behaviours that include aggression and violence, but causality cannot be determined. The majority of available evidence is limited to cross-sectional studies and this makes it difficult to speculate on the plausible mechanisms linking consumption to mental health outcomes. For example, mental health outcomes such as depression and anxiety may induce caffeine consumption to promote feelings of well-being and energy [59]. Furthermore, caffeine consumption is associated with sleep disorders [49] including sleep duration and quality. While tiredness may in turn promote headaches, stomach-aches, mental health, behavioural problems and poor attention, it may also encourage greater caffeine consumption to enhance feeling of well-being. It is feasible that the relationship between caffeine consumption and mental health and sleep disordersis bidirectional [56].

4. Discussion

4.1. Main Findings of the Study

This article attempts to provide a more detailed investigation regarding the casual mechanisms between the primary active ingredients of EDs (i.e. sugar and caffeine) and health behaviours and outcomes among 6-18year olds. The findings from this study revealed that the consumption of caffeine and sugar are associated with a multitude of serious adverse effects on young people's health with common adversities shared between the two ingredients. Indeed, the combination of these two substances has also been studied by Shimizu [59], who maintains that the effect of sugar and caffeine in combination were negative. It was argued that the levels of blood glucose rose and dropped shortly afterwards when the substances were combined, resulting in a rise of energy from the sugar and caffeine which would have the effect of a drop in blood sugar. This takes place over the space of a few hours, resulting in a cycle of cravings which accompany the swings. In addition to this, the series of swings produced a large imbalance of levels of blood glucose.

4.2. What Is Already Known on this Topic?

Sugars that are contained within ED's lead to health complications. SSBs have a high calorific value but few or no additional nutritional value [2]. The National Federation of State High School Associations, in 2008, cited the risks and drug interactions involved with EDs, while recommending water and sports drinks for rehydration [60]. Caffeine, in moderation, may be tolerated well by healthy adults; however, heavy consumption, including the use of EDs, has been associated with consequences such as stroke, seizures, and sudden death in some cases [2]. The caffeine content of EDs is on average three times greater than a cola drinks.

The caffeine content of soft drinks limited by the US Food and Drug Administration (FDA).However, as EDs are classified as dietary supplements, no such regulations apply [6]. The clinical toxicity of caffeine begins at dosages of 1,000 mg/ day while dosages below 400 mg are generally considered safe; dosages above 5,000 mg may be lethal [61]. Caffeine has a wide array of physiological effects including coronary and cerebral vasoconstriction, stimulation of skeletal muscle, and relaxation of smooth muscles [62]. Despite its negative effects, in low/moderate concentrations (12.5 to 100 mg) caffeine intake has been associated with improved cognition, exercise endurance, mood, and reaction time [63].

The use of caffeinated drinks as well as SSBs has been associated with mental health problems in children and adolescents, including depression, anxiety, stress, and distress levels [2]. Energy drink consumption has also been linked with higher risk of sleep disorders and substance use, with one study reporting higher violence rates[48]. In addition to these negative health effects of sugar, other concerns are related to attention deficit hyperactivity disorder (ADHD) in children. A study was carried out which aimed to test the hypothesis that sugary drinks were associated with ADHD in children [64]. The study concluded that children who consumed these beverages to a moderate degree had a 1.4 likelihood of developing the condition whilst those who consumed a high amount had a likelihood of 3.7. This was compared to those who did not consume any sugary drinks. It was also the case that similar results were produced when females were excluded from the study, which highlighted the negative correlation between the consumption of sugary drinks and the development of ADHD. Other studies have addressed the issue of sugar causing an increase in uric acid [65]. The study identified clinical studies which have reported an association between levels of serum uric acid and the development of diabetic nephropathy, hyperactive behaviours, and also an imbalance of cholesterol levels which could result in the development of heart diseases.

Given that high doses of caffeine have been linked to tachycardia, excessive consumption of EDs puts children at risk of intracardiac conduction abnormalities, arrhythmias and may also cause sudden death [2]. Apart from its acidic effects on enamel erosion and causing dentine hypersensitivity, caffeine interferes with intestinal calcium absorption and may have negative effects on bone mineralisation in children, as maximal calcium deposition in bone occurs during adolescence [2]. This is supported in the study by Pinto et al., who evaluated the influence of EDson the exposure of dentinal tubules and the removal of the smear layer[65]. The study concluded that EDs can be an important factor in causing cervical dentine hypersensitivity [65].

4.3. What This Study Adds

The review confirms that there is a limited evidence on the mechanisms and combined effects of sugar and caffeine on young people's health. To our knowledge, the present study is the first of its kind to investigate the associations and mechanisms of the main ingredients of EDs (sugar and caffeine) on the physical, mental, and behavioural well-being of young people. Figure 1 depicts the combined impact of caffeine and sugar on children's and adolescent's health and behavioural outcomes.

Findings indicate that caffeine use can lead to aggression while also effecting the mental health of consumers. Furthermore, it is associated with high blood pressure, early menarche, obesity and diabetes due to the added sugar content. Besides the mentioned health impacts of sugar, there are some additional health concerns that include ADHD, increase in uric acid levels, hyperactive behaviours, and imbalanced cholesterol level leading to heart disease. Although caffeine alone acts as an appetite suppressor, the excess sugar content contained within EDs has been associated with higher risks of obesity along with increased fat percentage and BMI levels. Dental erosion is one of the most common issues that most adults and children face upon consuming EDs, eventually resulting in the loss of hard tissue of the teeth due to the acids and sugars inherent in the energy drink [66]. Apart from a high sugar content, EDs also have a high erosive potential due to a low pH [66].

4.4. Limitations of This Study

There are several limitations. First, as most of the reviewed papers are cross-sectional in nature, it would be difficult to infer causation between consumption of sugar and caffeine and health outcomes. Second, because the initial searches were carried out between the years 1997 to 2017, it is possible that more recent studies have been missed.

5. Conclusion

This study set out to determine the adverse effects that consumption of energy drinks may have on the physical and mental health outcomes and behaviours of children and adolescents. Caffeine and sugar are the main ingredients in energy drinks and are each associated with adverse outcomes, broader than the outcomes typically captured in the existing ED literature. This broader range of adverse outcomes has implications for the design of public health interventions. In terms of policy, there is sufficient evidence to warrant the regulation of EDs in schools and university campuses and their restriction for adolescents. However, well-designed prospective studies and randomised controlled trials are required to consolidate the impact of energy drinks in relation to this broader range of outcomes.

Conflict of Interest Statement

The authors of this paper declare no conflict of interest.

Acknowledgments

MA acknowledges the financial support of the Saudi Embassy. The work was further undertaken with the support of The Centre for the Development and Evaluation of Complex Interventions for Public Health

Improvement (DECIPHer), a UKCRC Public Health Research Centre of Excellence. Joint funding (MR/KO232331/1) from the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, the Welsh Government and the Wellcome Trust, under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged.

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