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

Abstract: Caffeinated energy drink 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 defined 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 focusing on the behavioural, physical and mental health outcomes associated with EDs consumption and the two main ingredients, sugar (including glucose, sucrose and fructose) and caffeine with explication of causal mechanism linking ingredient to outcome where relevant. The population of interest was children and adolescents aged 6 to 18 years of age. A total of 33 studies were identified. EDs consumption was found to be associated with health problems including high blood pressure, cardiovascular disease, headaches, sleep disorder, substance use, stress and hyperactivity. The causal relationship could not be determined for all outcomes. The caffeine and sugar contained in EDs can promote adverse effects on children and adolescents. There is weak evidence that these effects could extend beyond physical health to educational attainment, mental health and substance use. Increased awareness, regulation, and further prospective studies are required.

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

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 grown rapidly worldwide, 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 294 mg per can [11]. In comparison, a double espresso coffee contains around 80 milligrams of caffeine and popular carbonated sugar sweetened beverages (SSBs) can contain 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

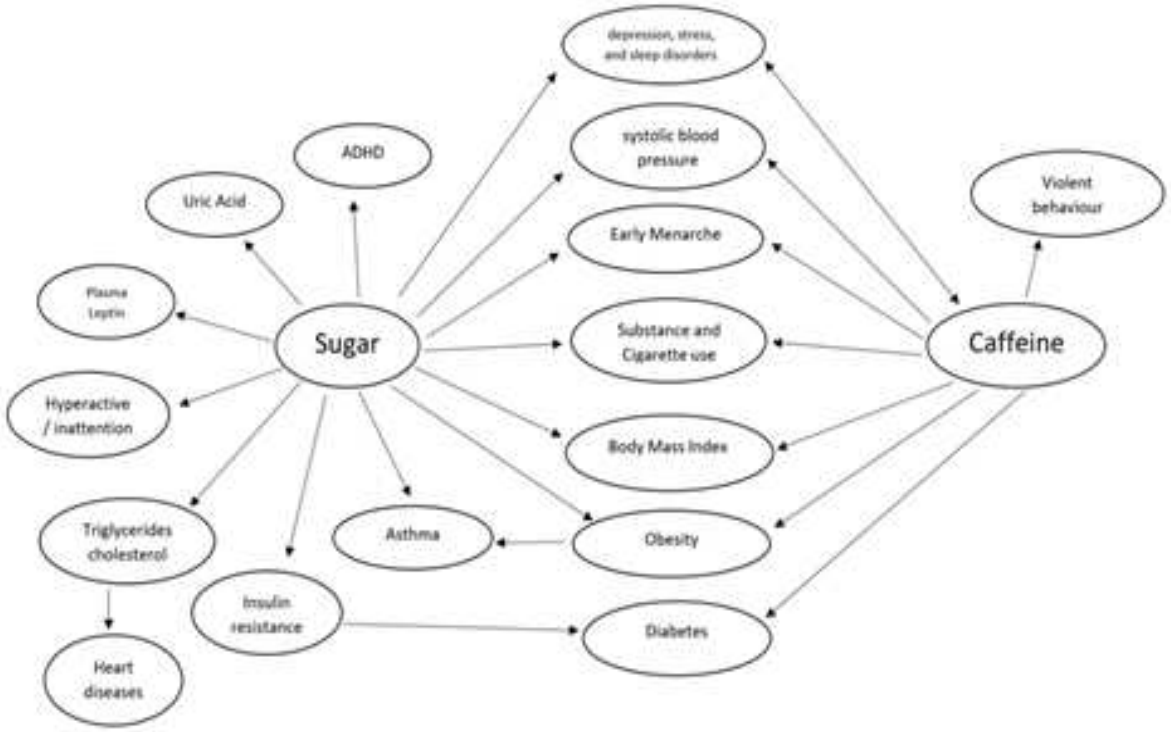

Figure 1. The effects of energy drinks on young people, based on the two active ingredients sugar and caffeine

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 therefore 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 percentages26 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]. Documented but less pertinent are studies indicating 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 respond adequately 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 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 disorders, substance use, mental health outcomes, asthma, cardiovascular disease, early menarche and tooth erosion.

2.2 Caffeine

The consumption of caffeine has been shown to be associated with depression, anxiety, stress [40], and lower academic achievement and sleep deprivation among adolescents [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 [43] and shorter sleep durations (≤ 8.5 hours) [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 have 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 vitally important, it is also necessary to consider whether there are feasible causal mechanisms

underpinning a documented relationship. For example, evidence has maintained that minimum unit pricing can reduce harms of specific products [66]. The study was based on the assessment leading to the UK Chancellor's announcement of a levy placed on sugar-sweetened beverages (SSBs). The move was largely welcomed in terms of its likeness to the minimum pricing per unit strategies that had been implemented to some success with other harmful products and was largely welcomed by those in the health profession. The study maintained that interventions such as these which were structured and also population-based had the effect of sending a message that a healthy diet cannot accommodate carbonated drinks. Accordingly, the proposition of the levy was such that it could provide a positive contribution to the general health of the population. However, criticisms within the same study maintained that those drinks which were exempt of the levy still contained sugar that could cause harm to teeth and general health. Whilst the levy was considered to be a positive beginning in the improvement of the diet of the nation, some improvements were suggested with the involvement of a lower threshold of exemption and a scaled volumetric tax of sugar that is added to products.

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 associated with diabetes is known to contribute to mental health problems such as depression, stress, anxiety, and sleep disorder, sleep deprivation can additionally increase the risk of stress [53] but stress can also lead to weight gain because overeating is a known coping mechanism [56]. There remains uncertainty on the relationship between sugar intake, stress, 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, for instance, whereas 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, resultantly causality cannot be determined. The majority of available evidence is limited to cross-sectional studies and therefore makes it difficult to speculate on the plausible mechanisms linking consumption to mental health problems. 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 disorders is bidirectional [56].

4. Discussion

4.1 Main findings of the study

This paper 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 6-18 year 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 [60], who maintains that the effect of sugar and caffeine in combination were negative on the body. 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 contained within ED's lead to severe health complications. SSBs are very high in calorific value and sugars, with few or no additional nutrients [2]. The National Federation of State High School Associations, in 2008, cited the risks and drug interactions involved with ED, while recommending water and sports drinks for rehydration [61]. Caffeine, in moderation, may be tolerated well by healthy adults; however, heavy consumption of it, 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 Cola drink content, with caffeine content in 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 [62]. Caffeine has a wide array of physiological effects including coronary and cerebral vasoconstriction, stimulation of skeletal muscle, and relaxation of smooth muscles [63]. 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 [64].

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 [65]. 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 [66]. 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., which evaluated the influence of EDs on the exposure of dentinal tubules and the removal of the smear layer [66]. The study concluded that EDs can be an important factor in causing cervical dentine hypersensitivity [66].

4.3 What this study adds

The review confirms that there is 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 cause violent behavioural patterns while also affecting the mental health of the consumer. 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 the uric acid, hyperactive behaviours, and imbalanced cholesterol level leading to heart diseases. 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].

4.5 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 – 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 physical and mental health outcomes and behaviours of children and adolescents. Caffeine and sugar are the main ingredients in energy drinks with consumption of the latter creating potential serious adverse effects on young people. The discussed adverse effects of energy drink consumption may have implications for the design of public health interventions. In terms of regulation, sales of energy drink should be prohibited in schools and university campuses and restricted for adolescents. Well-designed prospective studies and randomised controlled trials are required to consolidate the impact of energy drinks in relation to a wider range of outcomes.

Conflict of interest statement

The authors of this paper declare no conflict of interest.

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