REVIEW

The suitability of caffeinated drinks for children: a systematic review of randomised controlled trials, observational studies and expert panel guidelines

C. H. S. Ruxton

Nutrition Communications, Cupar, UK

Keywords
beverages, caffeine, child.

Correspondence
C. H. S. Ruxton, Nutrition Communications, 26 East Road, Cupar KY15 4HQ, UK.
Tel.: +79 73 337757
E-mail: carrie@nutrition-communications.com

How to cite this article
Ruxton C.H.S. (2013) The suitability of caffeinated drinks for children: a systematic review of randomised controlled trials, observational studies and expert panel guidelines. *J Hum Nutr Diet*.
doi:10.1111/jhn.12172

Abstract

Background: The increased availability of caffeinated drinks raises questions about the level of caffeine that is appropriate for children, as well as the benefits and risks associated with their consumption.
Methods: Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, this systematic review evaluates evidence from randomised controlled trials investigating the effects of caffeine on cognition, behaviour, mood and exercise performance in children. Observational studies and expert panel guidelines are also discussed.
Results: One hundred and nine studies were found, with 11 randomised controlled trials and 13 observational studies meeting the criteria. High caffeine intakes (e.g. >5 mg kg^{-1} body weight day^{-1}) were associated with an increased risk of anxiety and withdrawal symptoms. However, smaller amounts were not linked with such effects and may benefit cognitive function and sports performance based on adult studies. The evidence suggests that children and adolescents should limit daily caffeine consumption to 2.5 mg kg^{-1} body weight day^{-1}, equating to one or two cups of tea or one small cup of coffee. Lower contributors of caffeine, such as tea, may be more appropriate for children because they contribute to daily fluid intakes and provide flavonoids. By contrast, caffeinated soft drinks may be less suitable options for children as a result of their acidity, higher caffeine content, presence of added sugar (in some cases) and absence of bioactive compounds.
Conclusions: More studies are needed to determine the intakes that represent a risk and whether there may be benefits for alertness and sports performance with moderate intakes of caffeine.

Introduction

Caffeine (1,3,7-trimethylxanthine) is the most commonly used and socially acceptable psychoactive substance in the world and is consumed by all generations (Temple, 2009). However, its widespread availability in beverages has led to concerns about whether caffeine should be consumed by children and, if so, 'how much' is safe (Wierzejska, 2012). Blood caffeine levels generally peak approximately 30–120 min after oral ingestion, with a typical half-life of 3–6 h (Mort & Kruse, 2008), although genetic polymorphisms, amongst other factors, cause a wide variation in the individual responses to caffeine consumption (Yang *et al.*, 2010). Once absorbed, caffeine has broad effects on a variety of organs, including the brain, and its well-known impact on alertness may be attributed to the action of methylxanthine on serotonin neurones (Nehlig *et al.*, 1992). Caffeine exerts most of its biological effects by binding to all types of adenosine receptors, leading to modulation of brain functions relating to cognition, sleep, learning and memory (Ribeiro & Sebastião, 2010). The reported benefits of moderate caffeine consumption (e.g. 38–400 mg day^{-1}) in adults include improvements in physical endurance, cognitive function, including alertness and vigilance, and reduced perception of fatigue (Ruxton, 2008; Heckman *et al.*, 2010), although the effects of caffeine on the physiology and behaviour of children is not well understood (Temple, 2009).

Caffeine is found naturally in coffee beans, cacao beans, kola nuts, guarana berries and tea leaves, although coffee and tea are the primary sources (Heckman *et al.*, 2010). An American survey of participants aged 2–54 years showed that caffeine consumption increased with age, with the major sources of caffeine being coffee (71%), soft drinks (16%) and tea (12%). Although coffee was the main source of caffeine in adult diets, in children and teenagers, the main source was soft drinks (Frary *et al.*, 2005). Caffeine is also added to sports and energy drinks and there have been increasing concerns relating to their inappropriate use by children and the likely impact on energy intakes and weight gain (Committee on Nutrition & the Council on Sports Medicine & Fitness, 2011). A European survey of 37 500 children and adolescents, found that 18% children (aged 3–10 years) and 68% of adolescents (10–18 years) had consumed energy drinks (Zucconi *et al.*, 2013). Average intakes of caffeine were 23 mg day^{-1} [1.1 mg kg^{-1} body weight (BW)] in children and 149 mg day^{-1} in adolescents (2.4 mg kg^{-1} BW). Data specifically for UK adolescents ($n = 834$) showed a higher caffeine consumption of 190 mg day^{-1} (3.2 mg kg^{-1} BW) (Zucconi *et al.*, 2013). Table 1 presents the average caffeine levels found in standard portions of a variety of beverages. However, when interpreting the data, it should be considered that the caffeine content may vary considerably depending on brand, batch and mode of preparation. For example, an analysis of 20 commercial espresso coffees found that caffeine levels varied six-fold (Crozier *et al.*, 2012).

Table 1 Caffeine content of commonly consumed beverages with key health-related issues

Beverage (serving size)	Average caffeine content (mg per serving)	Range of caffeine content (mg per serving) where data are available
Average cup of tea* (190 mL)	50	1–90
Average cup of brewed coffee* (190 mL)	100	–
Average cup of instant coffee* (190 mL)	75	21–120
Chocolate milk† (230 mL)	5	–
Energy drinks† Small can (250 mL)	80	27–87
Large can‡ (500 mL)	150	60–170
Espresso coffee§ (single shot)	75	50–322
Filter/ground coffee† (190 mL)	105	15–254
Hot chocolate/cocoa† (150 mL)	–	1–6
Latte/Americano/Cappuccino† (350 mL)	150	–
Regular cola drink* (330 mL can)	40	30–60
Shot energy drinks† (60 mL)	80	80–175

*Data from Food Standards Agency (2004).
†Data extracted from key market brands.
‡Zucconi *et al.* (2013).
§Crozier *et al.* (2012).
SSB, sugar-sweetened beverages.
The wide variation in the caffeine content of tea and coffee can be explained by differences in the blend and brewing times.

Broader health implications

It is recognised that the indirect effects of caffeine on mood and concentration contribute to its cognitive-enhancing properties, although it cannot be regarded as a 'pure' cognitive enhancer (Nehlig, 2010). Caffeine has been found to have ergogenic properties when ingested in low-to-moderate doses (3–6 mg kg^{-1} BW), whereas further improvements in performance have not been observed beyond doses of ≥9 mg kg^{-1} BW (Goldstein *et al.*, 2010). In terms of broader health effects, caffeine has been found to increase energy availability and energy expenditure, reduce fatigue and the sense of effort associated with physical activities, enhance motor performance, and increase the speed and accuracy of reactions (Glade, 2010).

When consumed in moderation, caffeine can have positive effects on behaviour, although, in sensitive individuals, excessive intakes (defined in this instance as 'beyond regular use') may have health implications (Smith, 2002). For example, caffeine use has been linked with headaches when individuals have high intakes and repetitive exposures, leading to withdrawal headaches and dependency (Shapiro, 2008). In animal studies, caffeine appears to stimulate detrusor overactivity (muscles responsible for bladder control), leading to increased frequency of urine output (Kershen *et al.*, 2012), although findings from human studies have been conflicting. One intervention in patients with an overactive bladder reported early urgency and frequency of urination after caffeine intakes of 4.5 mg kg^{-1} BW (Lohsiriwat *et al.*, 2011) but another study in women with detrusor overactivity found no effect of caffeine restriction on voiding frequency, urgency and wetting (Swithinbank *et al.*, 2005). Further human trials are needed to investigate this further.

Caffeinated drinks have been linked to a risk of 'dehydration' in the popular press, although the evidence to support this view has arisen from interventions using caffeine pills providing doses far in excess of those typically consumed from caffeinated beverages [Food Standards Agency (FSA), 2004]. A randomised, controlled cross-over trial assessed hydration status in 21 healthy males after the consumption of four or six servings of tea (240 mL), providing 168 mg or 252 mg caffeine, respectively, compared with a boiled water control. Markers of normal hydration were compared, including blood osmolality, blood/urine electrolytes and urine volume, with no significant differences reported between treatment groups (Ruxton & Hart, 2011). Similar findings have been reported in other studies of caffeinated beverages (Grandjean *et al.*, 2000; Fiala *et al.*, 2004). In addition, a review of 41 randomised controlled trials (RCTs) demonstrated that most studies reported physical benefits when caffeine was ingested in moderation (37.5–450 mg day^{-1}), whereas intakes of up to 400 mg day^{-1} were not found to lead to adverse effects (Ruxton, 2008). Overall, it was concluded that 38–400 mg of caffeine, equivalent to 1–8 cups of tea or 0.3–4 cups of brewed coffee per day, appeared to maximise mental alertness and sports performance at the same time as minimising health risks (Ruxton, 2008).

Fewer studies of this type have been carried out on children and adolescents, resulting in poor knowledge about the effects of caffeine use on their behaviour and physiology (Temple, 2009). Caffeine is now increasingly available in commercial soft drinks designed for young people, with some caffeine-containing beverages being marketed to children as young as four years (Temple, 2009). In particular, there are growing concerns about rising rates of energy drink consumption amongst young people, with over 200 brands being available in more than 140 countries. Approximately 30% of adolescents report regular use (Oddy & O'Sullivan, 2010), whereas 12% can be classed as 'high chronic' users (Zucconi *et al.*, 2013). Unrestricted availability in retail outlets makes these types of drinks easily accessible to younger children (Cichocki, 2012).

Energy drinks, when consumed in excess, may increase the risk of caffeine toxicity (Wolk *et al.*, 2012), with the risk of symptoms being exacerbated when caffeine-containing medications or preparations are taken alongside (Rath, 2012). This is especially applicable to children and adolescents who are not habitual caffeine users and have failed to develop a pharmacological tolerance (Reissig *et al.*, 2009). Given the emerging concerns about caffeine ingestion in younger populations, this review aims to collate and evaluate evidence from RCTs investigating the effects of caffeine consumption on cognition, exercise performance and markers of normal hydration in children. Evidence from observational studies is also described, along with caffeine guidelines from expert bodies.

Materials and methods

A systematic literature review was conducted, according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (2013), which were used to select studies and provide guidance on the weight placed on studies, i.e. RCTs (Tables 2 and 3) were given more weight than observational studies (Table 4).

The following search strategy was used: MEDLINE database (PubMed) was searched for English language, peer reviewed human studies published between May 1983 and 2013 (Fig. 1), with the last check run on the 9 May 2013. The search was limited to studies looking at preschool children (2–5 years), children (6–12 years) and adolescents (13–18 years) using the database filter. The keyword search terms included: 'caffeine/caffeinated' in combination with 'cognition/cognitive function', 'behaviour', 'mood' and 'exercise' 'performance' or 'hydration'.

The following characteristics and inclusion criteria were used: (i) studies on preschoolers/children/teenagers; (ii) the caffeine intake/dose was reported; (iii) papers were randomised trials or observational studies; (iv) the study was not a combined multi-intervention; (v) access to the full text paper was available, either through PubMed or by contacting the author(s); and (vi) studies were corrected for alcohol intake where appropriate. The reference lists of scientific papers and reports were also hand searched to identify relevant papers. For the identification of studies, the search protocol included the stages: screening of identified papers; examination of the full text of potentially relevant studies; and application of the inclusion criteria to select the included studies. All reports were assessed by two reviewers for suitability.

In addition, a general Internet search was carried out using the key terms 'caffeine' combined with 'guidelines', 'recommended intakes/levels' and 'regulations' to locate recommendations regarding caffeine intake in children published by major international bodies and organisations dealing with nutrition in children.

Results

Cognition, behaviour and mood

There is a large literature base on the cognitive/behavioural effects of caffeine on adults but less is known about the impact on younger people (Temple, 2009). Six RCTs were found that investigated the effects of caffeine on cognition, behaviour and mood (Table 2). Studies varied in terms of their design, the range of cognitive measures and the dose of caffeine used. In one randomised crossover study, children with attention deficit hyperactivity disorder were provided with either two gelatine capsules, containing 80 mg of caffeine or a placebo, and their skin conductance levels (SCL; a marker of arousal) and behaviour were monitored. Although caffeine increased arousal in the present study, as indicated by a rise in SCL, the effect was nonsignificant. Further work using a larger sample size and different doses of caffeine is needed,

Table 2 Caffeine and children: randomised controlled trials: cognition, behaviour and mood

Study	Subjects	Study design	Caffeine intervention and dose	Outcome measures	Main findings
Barry *et al.* (2012)	Children (n = 18) with ADHD, 8–13 years	Randomised double-blind placebo-controlled repeated-measures cross-over study	Single oral dose of caffeine. Two sessions 1 week apart	SCL	Caffeine ↑ SCL, but no difference between groups. Caffeine-induced arousal ↑ in the ADHD group and was positively associated with hyperactivity/impulsivity levels
Heatherley *et al.* (2006)	Children (n = 26) 9–11 years Habitual caffeine consumers (mean caffeine intake = 109 mg day^{-1}) and non/low-consumers (12 mg day^{-1})	Double-blind, placebo-controlled study	Baseline, 50 mg of caffeine or placebo	Cognitive performance (number search task). Self-rated mood and physical symptoms, including alertness and headache	Few benefits from the caffeine, although among caffeine drinkers, caffeine prevented an increase in headache that followed after placebo and ↑ alertness relative to the placebo
Bernstein *et al.* (1998)	School-age children (n = 30)	Single-blind, within-subjects, repeated-measures study	Four sessions, 1 week apart, under four conditions: baseline; caffeine (approximately 120–145 mg day^{-1}); during withdrawal (24 h after discontinuation of caffeine taken for 13 consecutive days); at return to baseline	Self-report measures of symptoms and objective measures of attention, motor performance, processing speed and memory	During caffeine withdrawal, significant deterioration in response time to a visual test of attention
Bernstein *et al.* (1994)	Prepubertal children (n = 21)	Double-blind, randomised, placebo-controlled cross-over design	Four sessions, 1 week apart, under four conditions: baseline, placebo, 2.5 mg kg^{-1} caffeine and 5.0 mg kg^{-1} caffeine	Learning and performance, including measures of attention, manual dexterity, short-term memory and processing speed. Anxiety rating scales	Caffeine improved performance on two out of four attention measures. Children reported feeling significantly less sluggish after caffeine versus placebo ingestion
Baer (1987)	Preschool children (n = 6)	Reversal design, counter balanced for order of conditions	Baseline, caffeinated and noncaffeinated beverages	Direct observation of classroom behaviour including movement, sustained attention and memory	Caffeine exerted small, inconsistent effects on classroom behaviour
Rapoport *et al.* (1984)	Grade school children mean, 10.3 years [n = 19 high caffeine consumers (>500 mg day^{-1}) + n = 19 low consumers]	Double-blind, placebo-controlled, study using a cross-over design	5 mg kg^{-1} of caffeine twice a day or placebo for 2 weeks each	Anxiety questionnaire, autonomic arousal assessed by skin conductance, parental behaviour observations	High consumers receiving placebo had ↑ anxiety scores and lower autonomic arousal. Low consumers receiving caffeine perceived by parents as more emotional, inattentive and restless. No such change in high consumers receiving caffeine

ADHD, attention deficit hyperactivity disorder; SCL, skin conductance level.

Table 3 Caffeine and children: randomised controlled trials: physiology and performance

Study	Subjects	Study design	Caffeine intervention and dose	Outcome measures	Main findings
Turley *et al.* (2012)	Boys (n = 24), 8–10 years	Randomised double-blind, double cross-over, counter-balanced study	CAF (5 mg kg^{-1}) or PL twice each on four separate visits	Static hand-grip test Wingate test	Hand-grip reliability higher for CAF than PL. Mean power (180 ± 36 versus 173 ± 28 W) significantly higher ($P < 0.05$) in CAF versus PL group. Peak HR significantly higher in CAF versus PL group
Turley *et al.* (2008)	Children (n = 40)	Randomised, double-blind, counterbalanced study	PL, 1 mg kg^{-1} (CAF-1), 3 mg kg^{-1} (CAF-3), or 5 mg kg^{-1} (CAF-5) given 60 min prior to cycle ergometer exercise at 25W and 60% VO_2 peak	HR, VO_2, RER and BP at baseline and during exercise	No doses of caffeine had any effect on substrate use as reflected by RER. Caffeine intake ↑ BP and ↓ HR at baseline. There was a slight ↓ in HR with CAF-3 and CAF-5 versus PL during exercise
Turley *et al.* (2007)	Boys (n = 26), Men (n = 26)	Randomised, double blind, double cross-over study	CAF (5 mg kg^{-1}) or PL twice each on four separate days prior to cycle ergometer test at 25W and 50W	HR, VO_2 and BP at baseline and during exercise	BP not significantly affected by CAF. HR significantly ($P < 0.05$) lower at rest, 25W and 50W in CAF versus PL. During exercise, VO_2 and RER not different in CAF versus PL
Turley & Gerst (2006)	Children, 7–9 years (n = 52)	Randomised, double-blind, double cross-over study	PL or CAF (5 mg kg^{-1}) CAF twice each on four separate days prior to cycle ergometer test at 25W and 50W	HR, VO_2, RER and BP at baseline and during exercise	No impact on metabolism (VO_2 or RER) in young children at low-moderate intensities of exercise. CAF caused significantly lower HR and higher BP at rest and during exercise
Rapoport *et al.* (1981)	Boys mean age 9.8 years (n = 19)	Double-blind cross-over study	CAF (5 mg kg^{-1}) or PL twice a day for a 2-week period	Behaviour and autonomic reactivity	Caffeine ↑ autonomic reactivity of low users only. Behavioural and autonomic results ambiguous for high users indicating possible caffeine withdrawal symptoms

BP, blood pressure; CAF, caffeinated; HR, heart rate; PL, placebo; RER, respiratory exchange ratio; VO_2 peak, maximal oxygen consumption.

Table 4 Caffeine and children: observational studies

Study (Country)	Subjects	Study design	Outcome measures	Main findings
Kristjansson *et al.* (2013), USA	Adolescents aged 15–16 years (n = 3747)	Survey 10th graders enrolled in the Icelandic national education system	Caffeine use and self-reported violent behaviours and conduct disorders	Findings show links between caffeine consumption and violent behaviours/conduct disorders. Association significantly stronger for girls than boys
Calamaro *et al.* (2012), USA	Children aged 6–10 years (n = 625)	Survey using data from the NationalSleep Foundation's Sleep in America Poll	Caffeine intake, technology use, BMI and sleep duration	30% consumed a daily caffeinated beverage. Children who drank caffeinated beverages had 15 fewer minutes of sleep/night than nonconsumers (P = 0.002). Not controlled for confounders
Gunja & Brown (2012), Australia	Adolescents	Retrospective observational study	Energy drink exposures and symptoms Median energy drinks consumed in one session = 5 units	87% experienced symptoms – most common = palpitations, agitation, tremor, gastrointestinal upset. 21 subjects had signs of cardiac or neurological toxicity. However, alcohol commonly consumed alongside energy drinks
Benko *et al.* (2011), Brazil	Children and adolescents aged 9–12 years with depressive symptoms (n = 51) and nondepressed controls	Observational cross-sectional	Psychopathological symptoms assessed with the CDI	Depressed children (≥1.5 on CDI scale) consumed significantly more caffeinated drinks than nondepressed children
Drescher *et al.* (2011), USA	Adolescents aged 10–17 years (n = 319)	Cross-sectional study of a community based cohort	Electronic screen time, dietary and caffeine intake, parent-reported TST and BMI	TST inversely associated with BMI, electronic screen time and caffeine use, but findings differentially related to age. Caffeine consumption associated with ↓ TST in older adolescents. ↓ TST and ↑ caffeine intake and screen time may result in ↑ obesity risk in the adolescent population
Warzak *et al.* (2011), USA	Parents of young children aged 5–12 years (n = 228)	Observational study	Habitual caffeine intake from drinks. Hours slept. Frequency of bed wetting	Mean intakes of caffeine from beverages were 52 mg day^{-1} for children aged 5–7 years and 109 mg day^{-1} for those aged 8–12 years. Caffeine consumption and hours slept significantly negatively correlated
Calamaro *et al.* (2009) USA	Middle and high school subjects aged 12–18 years	Observational study	Caffeine intake, use of night time media-related technology and sleep behaviours	Adolescents used technology late into the night and concurrently consumed caffeinated beverages. Caffeine consumption 76% higher by those who fell asleep during school
Temple *et al.* (2009) USA	Adolescents aged 12–17 years	Double-blind, placebo controlled cross-over study	Operant responding to beverages. Behavioural checklist, a beverage-liking questionnaire and 24-h dietary recall	Males found caffeinated soda significantly more reinforcing than females after exposure period

Table 4 (*Continued*)

Study (Country)	Subjects	Study design	Outcome measures	Main findings
Libuda *et al.* (2008) Germany	Children and adolescents (n = 228)	Survey, children enrolled in the DONALD study	3-day weighed diet records. Bone modelling and remodelling assessed by peripheral quantitative computed tomography	Long-term consumption of all soft drinks/uncaffeinated soft drinks negatively associated with bone mineral content ($P < 0.05$), cortical area ($P < 0.05$) and polar strength strain index ($P < 0.05$), all of which reflect a combination of bone modelling and remodelling
Savoca *et al.* (2004) USA	White and African American adolescents (n = 159) in three categories of caffeine intake	Observational study	Blood pressure	African Americans consuming >100 mg day^{-1} caffeine had higher systolic blood pressure than groups consuming <100 mg day^{-1}
Pollak & Bright (2003) UDA	n = 191	Survey of 7th, 8th and 9th graders	2-week diary of sleep and caffeine intake	Mean use ranged up to 379.4 mg day^{-1} and averaged 62.7 mg day^{-1}. Higher caffeine intake associated with shorter nocturnal sleep duration, ↑ wake time after sleep onset and ↑ daytime sleep. Caffeine (soda) consumption ↑ on weekends for social reasons
Hering-Hanit & Gadoth (2003) Israel	Children/adolescents aged 9.2 years (n = 36) Heavy cola consumers (>1.5 L day^{-1}; 193 mg day^{-1} caffeine) with daily or chronic headache	Observational study	Frequency of headache assessed in clinic by clinicians following gradual withdrawal from consumption	Gradual caffeine withdrawal from cola drinks led to cessation of headaches in 33 subjects
Bernstein *et al.* (2002), USA	Teenagers consuming caffeine daily (n = 36)	Survey	Modified Diagnostic Interview Schedule for Children (DISC-IV) to assess caffeine dependence based on substance dependence criteria	42% reported tolerance to caffeine, 78% had withdrawal symptoms, 39% reported desire or unsuccessful attempts to control use, 17% endorsed use. No difference in amount of caffeine consumed daily by dependent versus nondependent teenagers

BMI, body mass index; CDI, Children's Depression Inventory; TST, total sleep time.

although mild stimulants such as caffeine may help to elevate arousal levels towards normal values in this population group (Barry *et al.*, 2012).

Other studies have looked at the effects of caffeine on learning and measures of school performance. One trial randomised habitual and non/low caffeine consumers ($n = 26$) to ingest a 125-mL fruit juice drink containing either 50 mg of caffeine or no caffeine. Accuracy of cognitive tests (a number search task; a marker of school performance) improved in the caffeine versus the placebo group amongst caffeine consumers ($P < 0.05$) but not in the non/low-consumers ($P > 0.1$), whereas more headaches were reported after the placebo (Heatherley *et al.*, 2006).

In a randomised cross-over study, 21 children took part in a baseline study and then received 2.5 mg kg^{-1}, 5.0 mg kg^{-1} caffeine or a placebo. Attention, dexterity and memory tests showed that caffeine improved performance on attention and motor task tests but led to some feelings of anxiety, although children felt less sluggish (Bernstein *et al.*, 1994). Another study, providing children ($n = 30$) with up to 145 mg caffeine day^{-1} for 13 days, showed that discontinuation of caffeine led to significant reductions in reaction times for tasks that required sustained attention (Bernstein *et al.*, 1998). Behavioural effects were also seen in a cross-over trial of children (mean age 10.3 years; $n = 38$) where 'high caffeine consumers' (500 mg day^{-1} or more) and 'low consumers' received 5 mg kg^{-1} BW caffeine twice a day or placebo for 2 weeks. When not receiving caffeine, high consumers had higher anxiety scores and reduced autonomic arousal, whereas low consumers receiving the caffeine were perceived by their parents as being more emotional, inattentive and restless, although high consumers were not rated as changed (Rapoport *et al.*, 1984).

Only one small study investigated the behavioural effects of caffeine ingestion on preschool children. In a 2-week cross-over study, 5-year old children ($n = 6$) took part in a baseline study (no drinks served) and then received a 200-mL serving of caffeinated, sugar-free cola providing 1.6–2.5 mg kg^{-1} BW caffeine, or a similar amount of a caffeine-free version. Results showed that that caffeine had small but inconsistent effects on reported classroom behaviour, defined as any behaviour that breached classroom rules, although the small sample size may have been a factor in this (Baer, 1987).

These studies suggest that caffeine habituation, dose, level of exposure and degree of withdrawal may influence how children respond to caffeine. Clearly, more well-designed studies are needed using the same randomised approach but larger sample sizes. There is also a need to study the effects of caffeine on children's behaviour from beverages as opposed to caffeine capsules, which create an artificial situation in terms of the speed of caffeine consumption, the amount consumed and associated fluid intake.

Exercise performance and hydration

Five studies investigated the effects of caffeine consumption on markers of exercise performance in children (Table 3), although no studies considered outcomes relating to hydration. Most studies looked at markers of exercise performance after participants were given a caffeine intervention. In one RCT, Turley *et al.* (2012) found that moderately high doses of caffeine (5 mg kg^{-1} BW) significantly increased the average power of 8–10-year-old boys ($n = 24$) during the Wingate test compared with a placebo ($P < 0.05$). A larger randomised study ($n = 40$) found that low and moderate doses of caffeine (1.3 or 5 mg kg^{-1} BW) did not have any significant effects on the utilisation of substrates measured using the respiratory exchange ratio (Turley *et al.*, 2008).

Another randomised trial ($n = 52$) tested whether sex differences affect caffeine response by allocating girls or boys (7–9 years) to receive a drink containing 5 mg kg^{-1} BW caffeine, or a placebo, on four different days, followed by ergometer cycling. This showed that moderate doses of caffeine did not affect metabolism, using similar measurements to Turley *et al.* (2008), although caffeine significantly lowered heart rate and raised blood pressure in both boys and girls (Turley & Gerst, 2006).

Other work has compared the effects of caffeine on physiological responses in men versus boys. Both groups were given a caffeinated (5 mg kg^{-1} BW) or placebo drink twice on four separate days followed by a cycling test on an ergometer at 25 and 50 W. Caffeine metabolism was similar when the two age groups were compared (i.e. no effects on respiratory exchange ratio; the ratio between the amount of carbon dioxide produced and oxygen consumed in one breath or levels of maximal oxygen consumption). Heart rate was significantly lower ($P < 0.05$) in children taking caffeine versus the placebo, although no such affects were seen in adults, which may relate to the greater likelihood of habitual use (Turley *et al.*, 2007). An earlier study by Rapoport *et al.* (1981) compared the cognitive and behavioural effects of single doses of caffeine (3 or 10 mg kg^{-1} BW) in prepubertal boys and college aged males ($n = 19$). Although the children showed signs of increased motor activity, speech rate and decreased reaction time after caffeine, the adults generally reported more side effects, especially amongst those with a low habitual caffeine intake.

On the whole, the findings from these studies are mixed. Physiological responses to caffeine ingestion in relation to exercise performance do not appear to vary between sexes (Turley *et al.*, 2007), or by age (Turley *et al.*, 2007). Further performance studies are needed, particularly on young females, who were under-represented in this body of research. It is also worth noting that the amounts of caffeine given are high in some studies (i.e. 5 mg kg^{-1} BW caffeine). This is the level at which the European Food Safety Authority (European Food Safety Authority, 2011) suggests adverse effects in children may occur.

Observational evidence

A total of 13 observational studies were found, with most (eight studies) conducted in the USA (Table 4). Six studies looked at the effects of caffeine in relation to sleeping patterns. A US survey using data from the Sleep in America poll found that approximately 30% of children aged 6–10 years had consumed a daily caffeinated beverage that was associated with 15 min less sleep per night ($P = 0.002$) compared with children not drinking these beverages (Calamaro *et al.*, 2012). Another observational study found that younger children (5–7 years) ingested less caffeine (52 mg of caffeine daily) compared with children aged 8–12 years (109 mg caffeine daily). Caffeine consumption and hours slept were significantly negatively correlated (Warzak *et al.*, 2011). Similarly, Drescher *et al.* (2011) reported that total sleep time was inversely related to caffeine use, especially amongst older adolescents, whereas Pollak & Bright (2003) found that high intakes of caffeine were associated with shorter nocturnal sleep duration, increased wake time after sleep onset, and increased daytime sleep depending on age and sex (mean caffeine intakes were in the range 62.7–379 mg day^{-1}).

It is important to note that most of these studies reported values as 'total caffeine' and failed to differentiate sources of caffeine. Thus, it is unknown whether the main sources of caffeine were energy drinks, tea, coffee, cola or chocolate, some of which would have other health implications, such as sugar content or low pH. Pollak & Bright (2003) reported that most caffeine came from soda consumption at weekends. This makes interpreting the findings from these studies rather difficult, especially because some of the age ranges were broad and included teenagers, who are known to be regular consumers of high caffeine energy drinks. Also, many of the observational studies are likely to be confounded by other factors that affect sleeping patterns. For example, Calamaro *et al.* (2009) found that caffeine consumption tended to be 76% higher by those who fell asleep at school. However, this was attributed to the concurrent effects of using multiple forms of technology late at night along with drinking caffeinated beverages. This indicates a need for more controlled studies where potential confounders such as technology use can be corrected for.

There are emerging concerns that energy drinks may have adverse health effects on young people, such as mood and behavioural disorders (Seifert *et al.*, 2011). When consumed in excess, caffeine, the main active ingredient found in energy drinks, has been associated with cardiac arrhythmias, tachycardia, raised blood pressure, vomiting, seizures, sleep disturbances, psychiatric disease, physiological dependence and even death (Wolk *et al.*, 2012), A US survey of 15–16-year-olds found that caffeine consumption was associated with violent behaviour and conduct disorders, mainly amongst girls (Kristjansson *et al.*, 2013), although it was not possible to establish whether this relationship was causal as a result of the observational nature of this study. Another retrospective study found that caffeinated products and alcohol were likely to be co-ingested with energy drinks, leading to increased reports of palpitations, agitation, tremor and gastrointestinal upset, although it cannot be confirmed whether these related to caffeine toxicity or alcohol intake (Gunja & Brown, 2012). Interestingly, the large European survey by Zucconi *et al.* (2013) found that 24% of UK adolescents (53% of energy drink consumers) reported adding alcohol to energy drinks, which indicates another health concern.

With regard to broader health concerns, a study of 51 children, aged 9–12 years, found that caffeine intake was associated with depressive symptoms, although the correlational nature of the data limited conclusions about cause and effect (Benko *et al.*, 2011). A double-blind randomised cross-over trial by Temple *et al.* (2009) found that boys were more likely to find caffeine reinforcing (more likely to get a rush and more energy) than girls. This has been supported by evidence obtained from an intervention trial (Temple *et al.*, 2010). In this trial, cardiovascular response and snack food intake were measured after the administration of 0, 50, 100 and 200 mg of caffeine, with the finding that boys were more likely to feel energetic and experience improved athletic performance when caffeine was ingested. One study of African American and Caucasian adolescents ($n = 159$) found that African Americans consuming more than 100 mg day^{-1} of caffeine had a higher systolic blood pressure than the groups consuming lower amounts, indicating that caffeine may increase blood pressure and hypertension risk in this population (Savoca *et al.*, 2004). Another study looked at the effects of caffeine consumption on bedwetting amongst children, with Warzak *et al.* (2011) reporting that caffeine consumption was not significantly correlated with the number of nights that children wet the bed ($P = 0.49$).

Other work has looked at effects of caffeine withdrawal. In one study, teenagers (n = 36) with some features of caffeine dependence were studied, and it was found that 41.7% reported tolerance to caffeine, 77.8% described withdrawal symptoms, 38.9% reported desire or unsuccessful attempts to control use, and 16.7% endorsed use despite physical or psychological problems associated with its consumption (Bernstein *et al.*, 2002). Another study found that children with daily or near-daily headaches were heavy cola drinkers, consuming at least 1.5 L of cola drinks per day (193 mg of caffeine daily), and an average of 11 L (range 10.5–21 L) of cola a week, although gradual withdrawal went some way to alleviating the headaches that may have been related to the caffeine or other ingredients in the drinks (Hering-Hanit & Gadoth, 2003). There is also some emerging evidence that caffeine doses of 200–500 mg may have adverse effects on blood glucose control in patients with type II diabetes, although these studies have predominately been conducted on adults and the impact of timing and dose of caffeine are unclear (Whitehead & White, 2013).

High intakes of caffeine appear to affect sleeping patterns and may have negative effects on wellbeing. However, it is important to note that UK and European studies are lacking, with most work being conducted in the USA where patterns of caffeine consumption may differ. In addition, when considering sleeping patterns, studies often fail to separate the contribution of dietary and beverages sources of caffeine from the impact of potential confounders (e.g. stimulants such as taurine and excess use of technology).

Guidelines for children

A summary of expert body caffeine recommendations for children is shown in Table 5. At present, there are no specific caffeine guidelines for children in the UK apart from general advice for children and people sensitive to caffeine to consume caffeine in moderation. The Children's Food Trust's (2012) advised that children should avoid drinks or foods with added caffeine or other stimulants because it is considered they may disrupt children's sleep, behaviour and concentration. The European Scientific Committee on Food (2003) suggested that children who consume energy drinks instead of cola or other soft drinks may increase their daily caffeine intake which, in turn, could lead to behavioural changes, such as increased arousal, irritability, nervousness or anxiety. When considering the evidence for caffeine and mental performance, European Food Safety Authority (2011) commented that intakes of 5 mg kg^{-1} BW in children could increase the risk of transient behavioural changes (e.g. increased arousal, irritability, nervousness or anxiety).

The Dietitians of Canada (2012) guidelines focus on energy drinks, suggesting that these are not recommended because they provide no additional benefit to the diet, at the same time noting that approximately 25–30% of adolescents regularly consume these. For children and adolescents, it is advised that caffeine intakes should not exceed 2.5 mg kg^{-1} day^{-1}. Health Canada (2011) uses similar guidelines, advising that children aged 12 years and under should consume no more than 2.5 mg kg^{-1} BW, whereas children older than this may benefit from the same caffeine restriction given that the maximum adult caffeine dose may be inappropriate during growth and development. The panel expressed concern about the over use of caffeinated energy drinks by children, recommending limiting the amount of caffeine to a maximum of 400 mg L^{-1} or 180 mg per single serving. They also emphasised the need for more explicit labelling, stating that labels should identify energy drinks as being a 'high source of caffeine' and state 'not recommended for children, pregnant or breastfeeding women, and individuals sensitive to caffeine' and 'do not mix with alcohol' (Health Canada, 2011).

Australian guidelines are more varied. Food Standard Australia/New Zealand (2000) suggested that there is a lack of evidence about the health effects of caffeine ingestion in children and that there appears to be no reason why children might be more sensitive to caffeine than adults given that the rate of caffeine clearance is up to two-fold higher in prepubescent children compared with nonsmoking adults.

The International Society of Sports Nutrition (Campbell *et al.*, 2013) and Committee on Nutrition & the Council on Sports Medicine & Fitness (2011) both recognised the potential adverse effects of energy drinks, advising that children and teenagers seek approval from their parents before consumption. Parents are advised to recognise how energy drinks may impact on health and to discourage their use by children if they have underlying medical conditions, such as diabetes. It is also emphasised that sports and energy drinks are different products and their terminology should not be used interchangeably.

Labelling law

From December 2014, the new European Food Information Regulation (EU) 1169/2011 will require ready-to-drink beverages with a high caffeine content (in excess of 150 mg L^{-1} caffeine) to be labelled as 'not recommended for children, pregnant or breastfeeding women', although this does not apply to infusions such as tea (FSA, 2013) which, in any case, are generally lower in caffeine. Foods will also need to be labelled 'Contains caffeine. Not recommended for children or pregnant women' where

Table 5 Expert body caffeine recommendations for children

Body	Summary of recommendations
Children's Food Trust's (2012), UK	Avoid tea, coffee, cola and other drinks or foods with added caffeine or other stimulants. These are not recommended for young children because caffeine is a stimulant that can disturb children's sleep, behaviour and concentration
Food Standards Agency (2013), UK	Children or people sensitive to caffeine should only consume this in moderation Drinks containing more than 150 mg L^{-1} caffeine should be labelled as 'high caffeine'
EU Food Information Regulation, EU	Drinks with a high caffeine content (in excess of 150 mg L^{-1} caffeine) are labelled as 'not recommended for children, pregnant or breastfeeding women' This does not apply to tea or coffee
European Food Safety Authority (2011), EU	Intakes of 5 mg kg^{-1} body weight in children could increase the risk of transient behavioural changes (e.g. increased arousal, irritability, nervousness or anxiety)
European Scientific Committee on Food (2003), EU	For children who do not normally consume much tea or coffee, and who might substitute 'energy' drinks for cola or other soft drinks, the consumption of 'energy' drinks might represent an increase in daily caffeine exposure compared with their previous intake, which may lead to behavioural and mood changes
Dietitians of Canada (2012), Canada	Survey research, primarily from the USA, has reported that one quarter to one third of adolescents regularly consume energy drinks. Energy drinks are not recommended for children and adolescents. There is currently no evidence to support that energy drinks are an important or beneficial addition to the diet For children and adolescents, caffeine intakes should not exceed 2.5 mg kg^{-1} day^{-1}
Health Canada Expert Panel on Caffeinated Energy Drinks (2011), Canada	For children aged 12 years and under, no more than 2.5 mg kg^{-1} body weight should be consumed. Based on the average body weight of children, this means a daily caffeine intake of no more than: Aged 4–6 years: 45 mg Aged 7–9 years: 62.5 mg Aged 10–12 years: 85 mg Advice for adolescents aged 13 years and older does not exist as a result of insufficient data
Dietitians Association of Australia (2013)	There is no need for children to have any caffeine. Parents and carers should monitor how much their children are having and cut back if they notice sleeping problems, anxiety or irritability
Food Standard Australia/New Zealand (2000)	The literature on caffeine in children is inadequate to make conclusions about behavioural effects
International Society of Sports Nutrition (Campbell *et al.*, 2013), USA	Children and adolescents should only consider use of energy drinks with parental approval after consideration of the amount of carbohydrate, caffeine and other nutrients contained in the energy drink/shot and a thorough understanding of the potential harmful side effects Diabetics and individuals with pre-existing cardiovascular, metabolic, hepatorenal and neurologic disease who are taking medications that may be affected by high glycaemic load foods, caffeine and/or other stimulants should avoid use of energy drinks and/or energy shots unless approved by their physician
Committee on Nutrition and the Council on Sports Medicine and Fitness (2011), USA	Recognise that sports drinks and energy drinks are significantly different products, and that these terms should not be used interchangeably A rigorous review and analysis of the literature revealed that caffeine and other stimulant substances contained in energy drinks have no place in the diet of children and adolescents

caffeine has been added for physiological purposes. Both of these statements, for beverages and foods, should be in the same field of vision as the name of the brand followed by the amount of caffeine in mg mL^{-1} or mg 100 g^{-1}. These guidelines do not apply to foods or drinks where caffeine has been added for flavouring rather than for physiological purposes. In these instances, the term 'caffeine' must appear after the word 'flavouring(s)' in the ingredients list (European Commission, 2011).

Discussion

Overall, the findings from this systematic review and summary of expert panel guidelines indicate that, when consumed in moderation, caffeine is unlikely to cause any harmful effects. It is advised, however, that intakes should be restricted to no more than 2.5 mg kg^{-1} BW per day to maximise benefit and minimise any risk in relation to behaviour, mood or sleeping patterns for children aged four years and older (Health Canada, 2011). Taking the

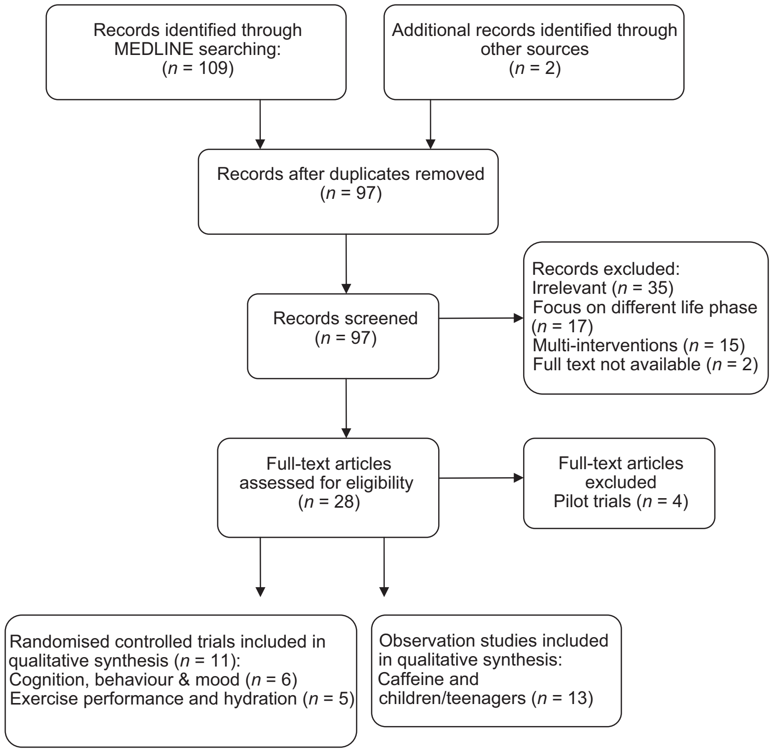

Figure 1 Systematic review process.

average body weight of a 5-year-old (20 kg), 10-year-old (32 kg) and 16-year-old (57 kg) girl from UK growth charts (Royal College of Paediatrics & Child Health, 2013), this would translate as an appropriate daily caffeine intake in the range 50–140 mg. At the lower end, this would equate to 1½ cups of tea (40–50 mg per serving), one small cup of instant coffee (75 mg per serving) or 1½ cans of cola drinks being consumed, although the high sugar content of certain soft drinks should be considered. There is no consensus in the UK about the age at which children can consume caffeinated drinks or how much caffeine may be appropriate or safe at different ages, although it has been suggested that strong caffeinated drinks, such as brewed coffee or energy drinks, are likely to contain too much caffeine for younger children (Ruxton, 2009).

As Table 1 shows, compared with other caffeinated beverages, tea has a low caffeine content which does not increase with portion size as long as tea bags are used (Ruxton & Hart, 2011). Tea is also an important source of bioactive compounds, including flavonoids and L-theanine, a naturally occurring nonprotein amino acid that has been found to improve concentration and learning ability (Vuong *et al.*, 2011). There is emerging evidence from preclinical trials that tea flavonoids help to support oral health, protecting against caries and periodontitis (inflammation around the tooth) (Varoni *et al.*, 2012).

It is open to debate whether sports and energy drinks offer any benefits to children and adolescents and the potential impact on energy intakes and obesity risk should be considered (Committee on Nutrition & the Council on Sports Medicine & Fitness, 2011). *In vitro* work indicates that the acidic pH of energy drinks means they have a high erosive potential (Cavalcanti *et al.*, 2010). As shown in Table 1, energy drinks differ widely in their caffeine content and care should be taken to moderate caffeine intake from other sources (e.g. medications and other beverages) when energy drinks are consumed regularly (Rath, 2012). Energy drinks can also contain sugar, thus having potentially negative effects on dental health (Cavalcanti *et al.*, 2010).

Popkin *et al.* (2006) developed a system that ranked all beverages on a scale of one to six, based on calorie and nutritional composition, and related health benefits versus risks. Water was given the most favourable rating of one, whereas unsweetened tea and herbal infusions were all given a rating of two, while sugar-sweetened soft drinks had the worst rating. The overall advice was that the consumption of beverages containing zero or few calories should take precedence over the ingestion of beverages with higher energy values. In the UK, a healthy hydration model has been published by the British Nutrition Foundation for children aged 4–13 years. This advises that unsweetened weak tea (up to two cups per day) for younger children is safe. Children can also opt for decaffeinated versions of tea but children should be encouraged to drink these with milk and no sugar (British Nutrition Foundation., 2013). Also, to improve iron absorption, it is best to offer weak, unsweetened tea between (rather than with) meals (NHS, 2011), although the Scientific Advisory Committee on Nutrition (2010) report that this is mainly of concern to individuals with low iron stores because most individuals have replete stores and would not see any impact on iron status from tea consumption.

The limitations of this systematic review are that studies on caffeine, cognition, behaviour and mood have mostly originated from the USA using varying methodologies, as well as different caffeine doses and study timescales. Equally, findings from studies investigating the effects of caffeine on exercise performance are mixed and limited in their design, making firm conclusions impossible. The most consistent evidence appears to come from observational studies, linking high intakes of caffeine to impaired sleeping patterns, although the design of these is vulnerable to confounding and cause–effect cannot be established. Finally, despite the lay view that caffeine may act as a diuretic, studies in adults have not found such an effect and no studies have investigated the impact of caffeine consumption on markers of normal hydration or frequency of urination in children.

Additional limitations are that many of the available studies had small sample sizes and did not cover all age groups. The use of differing cognitive, behaviour and mood tests also makes direct comparisons difficult. The issue of whether caffeine merely reverses withdrawal symptoms or confers a real cognitive benefit remains controversial and is hard to resolve, particularly because most children are now exposed to some dietary caffeine (Heatherley *et al.*, 2006). Finally, there are difficulties in translating any caffeine ranges from experimental evidence to real life as a result of differences in body weight (i.e. ranges are normally expressed per kg) as well as the diversity of caffeine sources.

Conclusions

The available evidence and expert panel opinions suggest that caffeine intakes of 2.5 mg kg^{-1} BW may be considered appropriate for children who are aged four years and above. When caffeinated beverages are consumed, these should be weak in concentration and unsweetened. Translating these guidelines, this equates to one or two cups of tea or one small cup of instant coffee for younger children, and two or three cups of tea or one or two small cups of instant coffee for older school-age children. Moderately caffeinated drinks, such as tea, may represent a healthier choice for children because tea is a major source of flavonoids and contributes to fluid intakes, thus helping to maintain normal hydration. Higher intakes of caffeine may be associated with agitation, anxiety and disrupted sleeping patterns, although these effects have not been attributed to tea/coffee consumption *per se* and studies finding such associations are limited in their design and sample sizes. There is a need for more rigorously designed studies to consider the broader implications of caffeine consumption in young children and adolescents, with an emphasis on sports performance and cognitive effects. Finally, work is needed on the impact of coffee and energy drinks, which tend to contain far more caffeine per serving than tea and cola. An expert review in the UK would be a welcome addition to the debate, giving much needed guidance to health professionals.

Ethical approval

Ethical approval was not deemed relevant for this review.

Conflict of interests, source of funding and authorship

Dr Ruxton serves as a paid member of the Tea Advisory Panel.

Funding for the present study was provided by the Tea Advisory Panel, which is supported by an unrestricted educational grant from the UK Tea Council, the trade association for the UK tea industry. Further information is available at http://www.teaadvisorypanel.com. The content of this paper reflects the opinion of the author. CHSR researched and wrote the paper, critically reviewed the manuscript and approved the final version submitted for publication. The assistance of Dr Emma Derbyshire in assessing manuscripts for suitability is gratefully acknowledged.

References

Baer, R.A. (1987) Effects of caffeine on classroom behavior, sustained attention, and a memory task in preschool children. *J. Appl. Behav. Anal.* **20**, 225–234.

Barry, R.J., Clarke, A.R., McCarthy, R., Selikowitz, M., MacDonald, B. & Dupuy, F.E. (2012) Caffeine effects on resting-state electrodermal levels in AD/HD suggest an anomalous arousal mechanism. *Biol. Psychol.* **89**, 606–608.

Benko, C.R., Farias, A.C., Farias, L.G., Pereira, E.F., Louzada, F.M. & Cordeiro, M.L. (2011) Potential link between caffeine consumption and pediatric depression: a case–control study. *BMC Pediatr.* **11**, 73.

Bernstein, G.A., Carroll, M.E., Crosby, R.D., Perwien, A.R., Go, F.S. & Benowitz, N.L. (1994) Caffeine effects on learning, performance, and anxiety in normal school-age children. *J. Am. Acad. Child Adolesc. Psychiatry* **33**, 407–415.

Bernstein, G.A., Carroll, M.E., Dean, N.W., Crosby, R.D., Perwien, A.R. & Benowitz, N.L. (1998) Caffeine withdrawal in normal school-age children. *J. Am. Acad. Child Adolesc. Psychiatry* **37**, 858–865.

Bernstein, G.A., Carroll, M.E., Thuras, P.D., Cosgrove, K.P. & Roth, M.E. (2002) Caffeine dependence in teenagers. *Drug Alcohol Depend.* **66**, 1–6.

British Nutrition Foundation. (2013) *Hydration for Children*. Available at: http://www.nutrition.org.uk/healthyliving/hydration/hydration-for-children (accessed on 8 May 2013).

Calamaro, C.J., Mason, T.B. & Ratcliffe, S.J. (2009) Adolescents living the 24/7 lifestyle: effects of caffeine and technology on sleep duration and daytime functioning. *Pediatrics* **123**, e1005–e1010.

Calamaro, C.J., Yang, K., Ratcliffe, S. & Chasens, E.R. (2012) Wired at a young age: the effect of caffeine and technology on sleep duration and body mass index in school-aged children. *J. Pediatr. Health Care* **26**, 276–282.

Campbell, B., Wilborn, C., Bounty, P., Taylor, L., Nelson, M.Y., Greenwood, M., Ziegenfuss, N.T., Lopez, L.H., Hoffman, J.R., Stout, J.R., Schmitz, S., Collins, R., Kalman, D.S., Antonio, J. & Kreider, R.B. (2013) International Society of Sports Nutrition position stand: energy drinks. *J. Int. Soc. Sports Nutr.* **10**, 1.

Cavalcanti, A.L., Costa Oliveira, M., Florentino, V.G., dos Santos, J.A., Vieira, F.F. & Cavalcanti, C.L. (2010) Short communication: *in vitro* assessment of erosive potential of energy drinks. *Eur. Arch. Paediatr. Dent.* **11**, 253–255.

Children's Food Trust. (2012) *Voluntary Food and Drink Guidelines for Early Years Settings in England – A Practical Guide*. Available at: http://www.childrensfoodtrust.org.uk/assets/eat-better-start-better/CFT%20Early%20Years%20Guide_Interactive_Sept%2012.pdf (accessed on 4 May 2013).

Cichocki, M. (2012) Energy drinks and their contribution to current health concerns for children and adolescents. *Przegl. Lek.* **69**, 854–860.

Committee on Nutrition and the Council on Sports Medicine and Fitness. (2011) Sports drinks and energy drinks for children and adolescents: are they appropriate? *Pediatrics* **127**, 1182–1189.

Crozier, T.W., Stalmach, A., Lean, M.E. & Crozier, A. (2012) Espresso coffee, caffeine and chlorogenic acid intake: potential health implications. *Food Funct.* **3**, 30–33.

Dietitians of Canada. (2012) *Energy Drinks Revisited*. Available at: http://www.pennutrition.com/docviewer.aspx?id=9886 (accessed on 4 May 2013).

Dietitians Association of Australia. (2013) *Caffeine*. Available at: http://daa.asn.au/for-the-public/smart-eating-for-you/nutrition-a-z/caffeine/ (accessed on 8 May 2013).

Drescher, A.A., Goodwin, J.L., Silva, G.E. & Quan, S.F. (2011) Caffeine and screen time in adolescence: associations with short sleep and obesity. *J. Clin. Sleep Med.* **7**, 337–342.

European Commission. (2011) *Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the Provision of Food Information to Consumers*. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:304:0018:0063:EN:PDF (accessed on 9 May 2013).

European Food Safety Authority. (2011) Scientific opinion on the substantiation of health claims related to caffeine and increased fat oxidation leading to a reduction in body fat mass, increased energy expenditure leading to a reduction in body weight, increased alertness and increased attention. *EFSA J.* **9**, 2054.

European Scientific Committee on Food. (2003) *Opinion of the Scientific Committee on Food on Additional Information on 'Energy' Drinks*. Available at: http://ec.europa.eu/food/fs/sc/scf/out169_en.pdf (accessed on 3 May 2013).

Fiala, K.A., Casa, D.J. & Roti, M.W. (2004) Rehydration with a caffeinated beverage during the nonexercise periods of 3 consecutive days of 2-a-day practices. *Int. J. Sport Nutr. Exerc. Metab.* **14**, 419–429.

Food Standard Australia/New Zealand. (2000) *Safety Aspects of Dietary Caffeine*. Available at: http://www.foodstandards.gov.au/consumer/whatsin/caffeine/pages/safetyaspectsofdieta890.aspx (accessed on 8 May 2013).

Food Standards Agency (FSA). (2004) *Survey of Caffeine Levels in Hot Beverages*. Available at: http://www.food.gov.uk/multimedia/pdfs/fsis5304.pdf (accessed on 3 May 2013).

Food Standards Agency (FSA). (2013) *High Caffeine Energy Drinks and Other Foods Containing Caffeine*. Available at: http://www.food.gov.uk/policy-advice/additivesbranch/energydrinks (accessed on 9 May 2013).

Frary, C.D., Johnson, R.K. & Wang, M.Q. (2005) Food sources and intakes of caffeine in the diets of persons in the United States. *J. Am. Diet. Assoc.* **105**, 110–113.

Glade, M.J. (2010) Caffeine-not just a stimulant. *Nutrition* **26**, 932–938.

Goldstein, E.R., Ziegenfuss, T., Kalman, D., Kreider, R., Campbell, B., Wilborn, C., Taylor, L., Willoughby, D., Stout, J., Graves, B.S., Wildman, R., Ivy, J.L., Spano, M., Smith, A.E. & Antonio, J. (2010) International society of sports nutrition position stand: caffeine and performance. *J. Int. Soc. Sports Nutr.* **7**, 5.

Grandjean, A.C., Reimers, K.J., Bannick, K.E. & Haven, M.C. (2000) The effect of caffeinated, non-caffeinated, caloric and non-caloric beverages on hydration. *J. Am. Coll. Nutr.* **19**, 591–600.

Gunja, N. & Brown, J.A. (2012) Energy drinks: health risks and toxicity. *Med. J. Aust.* **196**, 46–49.

Health Canada. (2011) *Health Canada's Proposed Approach to Managing Caffeinated Energy Drinks*. Available at: http://www.hc-sc.gc.ca/fn-an/legislation/pol/energy-drinks-boissons-energisantes-eng.php (accessed on 3 May 2013).

Heatherley, S.V., Hancock, K.M. & Rogers, P.J. (2006) Psychostimulant and other effects of caffeine in 9- to

11-year-old children. *J. Child Psychol. Psychiatry* **47**, 135–142.

Heckman, M.A., Weil, J. & Gonzalez de Mejia, E. (2010) Caffeine (1, 3, 7-trimethylxanthine) in foods: a comprehensive review on consumption, functionality, safety, and regulatory matters. *J. Food Sci.* **75**, R77–R87.

Hering-Hanit, R. & Gadoth, N. (2003) Caffeine-induced headache in children and adolescents. *Cephalalgia* **23**, 332–335.

Kershen, R., Mann-Gow, T., Yared, J., Stromberg, I. & Zvara, P. (2012) Caffeine ingestion causes detrusor overactivity and afferent nerve excitation in mice. *J. Urol.* **188**, 1986–1992.

Kristjansson, A.L., Sigfusdottir, I.D., Frost, S.S. & James, J.E. (2013) Adolescent caffeine consumption and self-reported violence and conduct disorder. *J. Youth Adolesc.* **42**, 1053–1062.

Libuda, L., Alexy, U., Remer, T., Stehle, P., Schoenau, E. & Kersting, M. (2008) Association between long-term consumption of soft drinks and variables of bone modeling and remodeling in a sample of healthy German children and adolescents. *Am. J. Clin. Nutr.* **88**, 1670–1677.

Lohsiriwat, S., Hirunsai, M. & Chaiyaprasithi, B. (2011) Effect of caffeine on bladder function in patients with overactive bladder symptoms. *Urol. Ann.* **3**, 14–18.

Mort, J.R. & Kruse, H.R. (2008) Timing of blood pressure measurement related to caffeine consumption. *Ann. Pharmacother.* **42**, 105–110.

Nehlig, A. (2010) Is caffeine a cognitive enhancer? *J. Alzheimers Dis.* **20**(Suppl. 1), S85–S94.

Nehlig, A., Daval, J.L. & Debry, G. (1992) Caffeine and the central nervous system: mechanisms of action, biochemical, metabolic and psychostimulant effects. *Brain Res. Brain Res. Rev.* **17**, 139–170.

NHS. (2011) *Iron and Your Diet*. Available at: http://hospital.blood.co.uk/library/pdf/2011_Iron_English.pdf (accessed on 8 May 2013).

Oddy, W.H. & O'Sullivan, T.A. (2010) Energy drinks for children and adolescents. *BMJ*. **340**, 64.

Pollak, C.P. & Bright, D. (2003) Caffeine consumption and weekly sleep patterns in US seventh-, eighth-, and ninth-graders. *Pediatrics* **111**, 42–46.

Popkin, B.M., Armstrong, L.E., Bray, G.M., Caballero, B., Frei, B. & Willett, W.C. (2006) A new proposed guidance system for beverage consumption in the United States. *Am. J. Clin. Nutr.* **83**, 529–542.

Rapoport, J.L., Elkins, R., Neims, A., Zahn, T. & Berg, C.J. (1981) Behavioral and autonomic effects of caffeine in normal boys. *Dev. Pharmacol. Ther.* **3**, 74–82.

Rapoport, J.L., Berg, C.J., Ismond, D.R., Zahn, T.P. & Neims, A. (1984) Behavioral effects of caffeine in children. Relationship between dietary choice and effects of caffeine challenge. *Arch. Gen. Psychiatry* **41**, 1073–1079.

Rath, M. (2012) Energy drinks: what is all the hype? The dangers of energy drink consumption. *J. Am. Acad. Nurse Pract.* **24**, 70–76.

Reissig, C.J., Strain, E.C. & Griffiths, R.R. (2009) Caffeinated energy drinks – a growing problem. *Drug Alcohol Depend.* **99**, 1–10.

Ribeiro, J.A. & Sebastião, A.M. (2010) Caffeine and adenosine. *J. Alzheimers Dis.* **20**(Suppl. 1), S3–S15.

Royal College of Paediatrics and Child Health. (2013) *UK-WHO Growth Charts*. Available at: http://www.rcpch.ac.uk/Research/UK-WHO-Growth-Charts (accessed on 10 September 2013).

Ruxton, C.H.S. (2008) The impact of caffeine on mood, cognitive function, performance and hydration: a review of benefits and risks. *Nutr. Bull.* **33**, 15–25.

Ruxton, C.H.S. (2009) Health aspects of caffeine: benefits and risks. *Nurs. Stand.* **24**, 41–48.

Ruxton, C.H.S. & Hart, V.A. (2011) Black tea is not significantly different from water in the maintenance of normal hydration in human subjects: results from a randomised controlled trial. *Br. J. Nutr.* **106**, 588–595.

Savoca, M.R., Evans, C.D., Wilson, M.E., Harshfield, G.A. & Ludwig, D.A. (2004) The association of caffeinated beverages with blood pressure in adolescents. *Arch. Pediatr. Adolesc. Med.* **158**, 473–477.

Scientific Advisory Committee on Nutrition. (2010) *Iron and Health*. London: The Stationery Office.

Seifert, S.M., Schaechter, J.L., Hershorin, E.R. & Lipshultz, S.E. (2011) Health effects of energy drinks on children, adolescents, and young adults. *Pediatrics* **127**, 511–528.

Shapiro, R.E. (2008) Caffeine and headaches. *Curr. Pain Headache Rep.* **12**, 311–315.

Smith, A. (2002) Effects of caffeine on human behavior. *Food Chem. Toxicol.* **40**, 1243–1255.

Swithinbank, L., Hashim, H. & Abrams, P. (2005) The effect of fluid intake on urinary symptoms in women. *J. Urol.* **174**, 187–189.

Temple, J.L. (2009) Caffeine use in children: what we know, what we have left to learn, and why we should worry. *Neurosci. Biobehav. Rev.* **33**, 793–806.

Temple, J.L., Bulkley, A.M., Briatico, L. & Dewey, A.M. (2009) Sex differences in reinforcing value of caffeinated beverages in adolescents. *Behav. Pharmacol.* **20**, 731–741.

Temple, J.L., Dewey, A.M. & Briatico, L.N. (2010) Effects of acute caffeine administration on adolescents. *Exp. Clin. Psychopharmacol.* **18**, 510–520.

Turley, K.R. & Gerst, J.W. (2006) Effects of caffeine on physiological responses to exercise in young boys and girls. *Med. Sci. Sports Exerc.* **38**, 520–526.

Turley, K.R., Desisso, T. & Gerst, J.W. (2007) Effects of caffeine on physiological responses to exercise: boys versus men. *Pediatr. Exerc. Sci.* **19**, 481–492.

Turley, K.R., Bland, J.R. & Evans, W.J. (2008) Effects of different doses of caffeine on exercise responses in young children. *Med. Sci. Sports Exerc.* **40**, 871–878.

Turley, K.R., Rivas, J.D., Townsend, J.R., Morton, A.B., Kosarek, J.W. & Cullum, M.G. (2012) Effects of caffeine on anaerobic exercise in boys. *Pediatr. Exerc. Sci.* **24**, 210–219.

Varoni, E.M., Lodi, G., Sardella, A., Carrassi, A. & Iriti, M. (2012) Plant polyphenols and oral health: old phytochemicals for new fields. *Curr. Med. Chem.* **19**, 1706–1720.

Vuong, Q.V., Bowyer, M.C. & Roach, P.D. (2011) L-Theanine: properties, synthesis and isolation from tea. *J. Sci. Food Agric.* **91**, 1931–1939.

Warzak, W.J., Evans, S., Floress, M.T., Gross, A.C. & Stoolman, S. (2011) Caffeine consumption in young children. *J. Pediatr.* **158**, 508–509.

Whitehead, N. & White, H. (2013) Systematic review of randomised controlled trials of the effects of caffeine or caffeinated drinks on blood glucose concentrations and insulin sensitivity in people with diabetes mellitus. *J. Hum. Nutr. Diet.* **26**, 111–125.

Wierzejska, R. (2012) Caffeine – common ingredient in a diet and its influence on human health. *Rocz. Panstw. Zakl. Hig.* **63**, 141–147.

Wolk, B.J., Ganetsky, M. & Babu, K.M. (2012) Toxicity of energy drinks. *Curr. Opin. Pediatr.* **24**, 243–251.

Yang, A., Palmer, A.A. & de Wit, H. (2010) Genetics of caffeine consumption and responses to caffeine. *Psychopharmacology* **211**, 245–257.

Zucconi, S., Volpato, C., Adinolfi, F., Gandini, E., Gentile, E., Loi, A. & Fioriti, L. (2013) *Gathering Consumption Data on Specific Consumer Groups of Energy Drinks*. Available at: http://www.efsa.europa.eu/en/supporting/doc/394e.pdf (accessed on 21 July 2013).