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Caffeine: Benefits and Risks for Health and Wellbeing

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Abstract

Background: Tea contains a variety of compounds, including caffeine, which have a range of health impacts. The presence of caffeine in tea often raises questions about the benefits of its consumption, including potential effects on cognition, behavior, mood and exercise performance as well as areas of concern such as anxiety, stress, hydration and heart health. The aim of this review is to evaluate the benefits and risks of caffeine consumption with a focus on tea and other compounds present in tea, which may interact with caffeine.

Methods: Evidence was considered from Randomised Controlled Trials (RCTs) published over the last 15 years investigating the effects of caffeine on cognition, alertness, behavior, hydration and mood. Systematic reviews, meta-analyses and expert panel reviews were included in the wider discussion.

Results: Evidence suggests that caffeine intakes of 3-6mg/kg/bw/(body weight)/day may benefit cognitive function and exercise performance in adults. Many expert bodies state that there are no safety concerns with daily intakes of ≤ 200mg caffeine in pregnant women and ≤ 400mg in other adults. Evidence indicates that children and adolescents should limit their daily caffeine intake to 2.5mg/kg/bw. Tea contains a lower concentration of caffeine than most other caffeinated drinks as well as providing fluid for hydration and polyphenolic compounds for health, particularly cardiovascular health. L-theanine in tea moderates the potential negative impact of caffeine on stress and anxiety whilst improving attention and speed of mental performance.

Conclusion: On balance, moderate amounts of caffeine provide benefits in terms of cognitive function, alertness and exercise performance in adults with minimal risk of adverse effects. Further research is required to determine safe, beneficial intakes in children and adolescents. Tea, with its lower caffeine content, in combination with flavonoid polyphenols, fluoride and L-theanine, may provide an acceptable benefit/risk ratio for people aged 4 years and over, assuming age-appropriate intakes of 1-8 daily servings.

Keywords: Caffeine; Cognitive function; Mental performance; Exercise performance; Tea; Flavonoids; Hydration

Introduction

Tea contains a range of polyphenolic compounds with established benefits for health, particularly cardiovascular health [1]. One particular tea constituent-caffeine-is often the subject of debate about whether it is helpful or harmful and the levels of intake that are appropriate for different life stages.

Caffeine Sources

Caffeine is a naturally occurring Central Nervous System (CNS) stimulant of the methylxanthine class (1,3,7-trimethylxanthine) and is the most widely taken psychoactive stimulant in the world [2]. Caffeine is found naturally in coffee beans, cacao beans, kola nuts, guarana berries as well as tea leaves, although coffee and tea are the primary sources in the UK diet. Caffeine is also added to sports and energy drinks and to some carbonated drinks. The caffeine content of commonly consumed beverages is found in (Table 1).

Metabolism

Caffeine is rapidly and completely absorbed in humans, with 99% absorbed within 45 minutes of consumption. Peak plasma caffeine concentrations occur between 15 and 120 minutes after oral intake, with a half-life range of 1.5-9 hours [3]. This wide variation is likely due to variation in gastric emptying time and the presence of other dietary constituents in the gastrointestinal tract such as fibre.

Once caffeine is absorbed, it passes directly from the gut to the blood circulation where it binds irreversibly to plasma proteins. The liver does not remove caffeine as it moves from the gut to the circulation, that is there is no hepatic first-pass effect. Caffeine binds reversibly to plasma proteins and the protein-bound caffeine accounts for 10-30% of the total plasma pool [4]. Caffeine appears to be both hydrophilic and lipophilic in that it both distributes freely into intracellular tissue water and is also able to pass through all biological lipid membranes including the blood-brain barrier. Once inside the

Table 1: Caffeine content of commonly consumed beverages.

Beverage	Average caffeine content (mg per serving)	Range of caffeine content (mg per serving) where data are available
Average cup of black tea (220ml) [58]	42	37-46
Average cup of green tea (190ml) [94]	30	25-50
Average cup of matcha green tea (2.1g of powder per serving) [13]	72.5	
Average cup of yerba mate (3g of loose tea per serving) [95]	40.5	22.5-40.8
Average cup of decaffeinated black tea (190ml) [96]	2	
Average cup of white tea (190ml) [97]	34	32-37
Average cup of oolong tea (2g of loose tea per serving) [98]	16	-
Average cup of herbal/fruit teas (Rooibos, Chamomile, Ginger, Hibiscus, Mint)	0	-
Average cup of brewed coffee (190ml)	100	
Average cup of instant coffee (190ml)	75	21-120
Average up of decaffeinated coffee (190ml)	2-15mg	2-10
Chocolate milk (230ml)	5	-
Energy drinks:	-	-
Small can (250ml)	80	27-87
Large can (500ml)	150	60-170
Espresso coffee (single shot)	75	50-232
Filter/ground coffee (190ml)	105	15-254
Hot chocolate/cocoa (150ml)	-	1-6
Latte/Americano/Cappuccino (350ml)	150	-
Regular cola drink (330ml can)	40	30-60
Shot energy drinks (60ml)	80	80-175

Reproduced from [93] Ruxton (2014); except: [58], Ruxton & Hart (2011); [94], Unno, et al. (2017), [4], Baba, et al. (2021); [95], Panzl, et al. (2022), [96], manufacturers' information; [97], Chin, et al. (2008); [98], Boros, et al. (2016). Note that the tea preparation methods used by Panzl, et al. (2022) and Boros, et al. (2016) involved longer brewing times and more robust extraction compared with home preparation which could result in higher caffeine levels.

brain caffeine blocks the effects of adenosine [3]. Caffeine is mainly metabolised in the liver through the cytochrome P450 enzyme system specifically through the activity of CYP1A2 [5]. This step accounts for up to 90% of caffeine metabolism. Paraxanthine is the chief metabolite and this has similar physiological and pharmacological effects to caffeine although it is less anxiolytic [3]. Two other metabolites of caffeine metabolism are theobromine and theophylline. All three metabolites are further broken down and excreted in the urine [6]. Because caffeine is readily re-absorbed by the kidney tubules, only a small proportion is excreted unchanged in the urine. Caffeine's clearance is affected by physiological and environmental factors, such as pregnancy, use of oral contraceptives and tobacco smoking.

Biochemical actions

Caffeine has several physiological and pharmacological effects, which are similar to those of other methylxanthines. These include cardiovascular, respiratory, renal and smooth muscle effects. Caffeine also impacts on alertness, memory, mood and cognitive and physical or athletic performance.

Mechanisms

Proposed mechanisms of action for caffeine differ depending on the physiological effects. Mechanisms of action include the antagonism of adenosine receptors, the inhibition of phosphodiesterase, the release of calcium from the cell stores and antagonism of benzodiazepine receptors [3]. The ability of caffeine to inhibit adenosine receptors appears to be highly important on its effects on behaviour and cognitive function as it increases mental attention by increasing cholinergic and dopaminergic transmission. This inhibition of adenosine receptors is also important for the action of caffeine on diuresis in the kidney, somewhat important for its effects on skeletal muscle - with phosphodiesterase, calcium mobilisation and its interaction with benzodiazepine receptors playing less significant roles in the mechanism of actions of caffeine. Caffeine is a fairly weak inhibitor of phosphodiesterase enzymes but may be strong enough to account for caffeine's stimulatory effects on the cardiovascular system, its relaxant effects on the respiratory system and its release of fuels such as free fatty acids in skeletal muscle [3].

Benefits of Caffeine

Moderate caffeine consumption (e.g., 38-400mg/day) in adults offers various benefits including improvements to physical endurance, cognitive function such as alertness and vigilance, and reduced perception of fatigue [7,8]. The effects of caffeine on the physiology

and behaviour of children are less well understood [9]. The relatively low doses of caffeine in black tea (on average <50mg per cup), green tea (on average 30mg), white tea and oolong tea would be expected to provide these health benefits when consumed in amounts of four cups daily, in the absence of adverse effects.

Study Assessments and Criteria

PubMed was searched for Randomised Controlled Trials (RCTs) over the last 15 years investigating the effects of caffeine on cognition, alertness, behaviour and mood. Because so much research on caffeine is now evaluated in the form of meta-analyses and systematic reviews we also searched for systematic reviews and meta-analyses under the same headings. We also identified expert panel reviews from different countries and regions throughout the world.

Mental Health and Cognitive Performance

Several controlled clinical trials have evaluated the impact of caffeine on mental health and cognitive performance (Table 2). All of the studies were conducted in a narrow population group, i.e. young adults and adolescents. Caffeine was provided mainly in the form of extracts [10-14] or in one case, a caffeinated drink. Findings from these studies are difficult to compare, because there was considerable variation in methodology, particularly outcomes measured. One looked at cognitive function from a battery of brain tests, including brain wave activity [15]. Another measured the impact of caffeine on sustained attention [10], another looked at reading skills, global perception and alertness [11] whilst another evaluated reaction time in e-gaming [14], and another mental reaction time [12]. Caffeine was found to improve mental and cognitive skills with effective doses of caffeine for these various outcomes across the randomised controlled trials ranged from3-6mg/kg/bw.

Several systematic reviews have evaluated the impact of caffeine on mental and cognitive function. See (Table 3). A systematic review including 61 observational (observational and controlled) studies in adults conducted between 1990 and 2020 looked at the association between caffeine and cognitive decline and/or dementia. Caffeine reduced the risk of dementia and cognitive decline and ameliorated cognitive decline in cognitively impaired people. Caffeine effects were more often positive when consumed in moderate quantities (100-400mg/d), consumed in coffee or green tea, and in women [16]. A systematic review of 13interventional trials involving athletes evaluating the impact of caffeine (3-6mg/kg/bw) on tests of cognitive function during exercise found significant effects of caffeine on attention, accuracy and speed. Caffeine also improved mood. [17].

Tea contains a range of constituents including polyphenolic

Table 2: Impact of caffeine on mental performance and cognitive health: randomised controlled trials.

Reference	Participants	Study design	Intervention	Outcomes	Findings
Ajjimaporn, et al. (2022) [15]	Healthy university students (n=25); mean age =21± 2 years	Randomised controlled crossover trial	50mg caffeinated drink or placebo	Brain wave activity, cognitive function (visuomotor processing speed, working memory and attention)	Cognitive function tests improved (p<0.05) after drinking caffeine drink
Cooper, et al. (2021) [10]	31 adolescents (aged 12-17; 15 female, 16 male; median caffeine intake=28mg/day	Randomised controlled trial	Placebo, 1mg/kg, or 3mg/kg caffeine (order counterbalanced)	Effect of caffeine on sustained attention	Improved sustained attention in a dose dependent fashion (i.e. 3mg/kg caffeine > benefit than 1mg/kg caffeine)
Franceschini, et al. (2020) [11]	Typical young adult readers. Two mechanistic studies (n=24 and n=53)	A double-blind, within-subjects, repeated-measures design	caffeine 200mg	Tests of reading skills, global and local perception, alerting, spatial attention and executive functions, as well as rapid automatised naming and phonological memory	Improvement in global processing and text reading skills in adults with caffeine
Sainz, et al. (2020) [14]	15 professional e-gamers (age=22 ± 3 years)	Double-blind, cross-over, randomized experimental trial	3mg/kg caffeine	Effect of acute caffeine intake on e-sports-specific performance	Caffeine decreased simple reaction time (0.20 ± 0.01 *vs*. 0.19 ± 0.01 s, P<0.01), the mean time taken to hit the targets (0.92 ± 0.07 *vs*. 0.88 ± 0.07 s, P<0.01) and enhanced hit accuracy (98.8 ± 0.92 *vs*. 99.8 ± 0.35% of targets hit, P<0.01)
Haller, et al. (2014) [12]	17 people with mild cognitive impairment compared to 17 healthy aged-matched controls(all caffeine consumers)	Double blind placebo controlled Magnetic Resonance Imaging (MRI) study	200mg caffeine after overnight abstinence	Cognition and brain activation in early phases of cognitive decline	Displacement of working memory-related brain activation patterns; may represent a compensatory mechanism to counterbalance frontal lobe dysfunction
Khcharem, et al. (2022) [13]	12 recreational runners	Double blind randomised controlled trial	6mg/kg caffeine	Physical or cognitive performance after sleep deprivation	Caffeine counterbalanced the effects of sleep deprivation.Reduced mental reaction time as well as improving running performance

Table 3: Impact of caffeine on mental performance and cognitive health: systematic reviews and meta-analyses.

Reference	Participants	Study design	Intervention	Outcomes	Findings
Chen, et al. (2020) [16]	61 studies from 24 countries	Systematic review of overall effects of caffeine (positive, negative or neutral) on cognitive health	Cross-sectional, longitudinal, case-control, controlled, cohort and pilot studies	The risk of dementia and/or cognitive decline	Risk of dementia & cognitive decline: 16/57 (28%) studies reported positive study outcomes (independent of study design) & 30/57 (53%) of studies showed positive outcomes dependent on study characteristics
	57 studies (153,070 subjects)			Cognitive performance in individuals with Mild Cognitive Impairment (MCI) or dementia	Cognitive function in cognitively impaired individuals: 3/4 studies reported positive outcomes. Caffeine effects more often positive when consumed in moderate amounts (100-400mg/day) in coffee, green tea & in women
	29 studies were based on coffee; 30 were based on tea; 15 based on multiple sources; 2 studies based on pure caffeine			To examine the effect of study characteristics (e.g. caffeine source and amount) on outcomes	
Lorenzo-Calvo, et al. (2021) [17]	13 RCTs Involved adult athletes (158 men and 36 women) who took part in elite, semi-professional or amateur sports activities.	Systematic review & meta-analysis	Doses of caffeine (5-60 minutes before testing): < 3 mg/kg in four studies, 3- 6 mg/kg/bw in eight, and different doses (2 and 4 mg/kg/bw in one. Studies used gum, capsules, drinks, or energy bars	Various tests of cognitive performance in sports (accuracy of attention; response accuracy; reaction time; response speed	Accuracy of attention (2 studies) greater with caffeine than placebo. Response accuracy (2 studies) greater with caffeine than placebo. No significant difference in reaction time (13 studies) with caffeine vs placebo No significant difference in response speed (2 studies) with caffeine vs placebo
Camfield, et al. (2014) [18]	11 RCTs	Systematic review & meta-analysis		Acute effects of tea constituents L-theanine and epigallocatechin gallate, administered alone or in combination with caffeine, on cognitive function and mood. Measures were: alertness, calmness, and contentedness, derived from the Bond-Lader scales, and state anxiety, from the State-Trait Anxiety Inventory	Combination of caffeine and L-theanine (2 hours post-dose) improved alertness, attentional switching accuracy & some attentional outcomes
Sohail, et al. (2021) [19]	6 controlled trials involving L-theanine/caffeine extracts; black tea; or matcha	Systematic review	Doses: 200-250mg L-theanine; 150-160mg caffeine		Favorable clinical significance in the domains of attention, memory, cognition, and hyperactivity

catechins (e.g., EGCG) and L-theanine as well as caffeine. A systematic review of 11 RCTs evaluating the acute effects of EGCG plus L-theanine with or without caffeine on cognitive function and mood found that the caffeine and L-theanine combination improved mental attention more than caffeine alone [18]. A further systematic review [19] came to the same conclusion that the increased attention associated with caffeine is enhanced by L-theanine. It is worth noting that these studies used pharmaceutical doses of L-theanine far in excess of the amounts found in beverages and, hence, represent more of a proof of concept rather than a naturalistic experiment.

Physical and Sports Performance

Intervention studies evaluating the impact of caffeine on aspects of physical and sports performance are summarised in (Table 4). These studies have generally found improvements in performance, but this is not universally so. Many of the trials have been conducted in young

Table 4: Impact of caffeine on physical/sports performance: randomised controlled trials (RCTs).

Reference	Participants	Study design	Intervention	Outcomes	Statistical significance
Arcoverde, et al. (2017) [20]	Nine healthy men undergoing exercise bouts	Randomised controlled crossover design	Caffeine extract 5mg/kg body weight	Anaerobic capacity, oxygen demand	No clear positive effect on anaerobic capacity and exercise endurance; Caffeine ingestion before submaximal trials did not affect supramaximal oxygen demand
Burke, et al .(2021) [21]	11 athletes (19.7 ± 0.9 yrs; 166.4 ± 10.2 cm, 67.7 ± 9.4 kg)	Randomised, double-blind trial	Caffeine extract 6mg/kg	Jumping performance (jump height) and strength (mid-thigh peak force)	Caffeine enhanced jump performance ($p<0.05$) but not maximal strength
Chen, et al. (2019) [22]	20 healthy (10 males, 10 females) college athletes	Randomised, double-blind trial	Caffeine extract 6mg/kg 24 and 48 hours after Exercise Induced Muscle Damage (EIMD)	Muscle performance, Delayed Onset Muscle Soreness (DOMS)	Reduction in EIMD and DOMS in both sexes with greater reduction in DOMS in males ($p> 0.05$) than females ($p>0.05$)
Duncan, et al. (2019) [23]	22 males	Double blind controlled trial	Caffeine 5mg/kg followed 60 minutes later by one upper body and one lower body Wingate Anaerobic Test (WANT)	Effect of caffeine on mean and peak power production, fatigue index and Rating Of Perceived Exertion (RPE) during upper body and lower body WANT performance	Caffeine ingested 60 minutes before anaerobic exercise significantly enhances peak power when data from upper and lower body WANTs are combined
Ferreira, et al. (2022) [24]	Recreationally resistance-trained participants (n=21)	Randomised controlled trial	Three experimental conditions: 6 mg/kg caffeine (CF6); 8mg/kg caffeine (CF8); or placebo (PLA), with a 7-day washout period between conditions	Muscular strength assessments for upper (squats) and lower body (bench presses)	Bench press, deadlift and squat strength were all significantly ($p < 0.001$) improved in CF8 compared to PLA
Filip-Stachnik, et al. (2021) [25]	Healthy resistance-trained female students (n=21) (23.0 ± 0.9 years, body mass: 59.0 ± 6.6 kg), with a daily caffeine intake of 5.8 ± 2.6 mg/kg/body mass	Randomised, crossover, double-blind trial	Three experimental conditions: 6 mg/kg caffeine (CF6); 8mg/kg caffeine (CF8); or placebo (PLA), with a 7-day washout period between conditions	Maximal strength and strength endurance	3-6mg/kg/b.m. of caffeine improves maximum strength, but no effect on strength endurance
Grgich, et al. (2017) [26]	17 volunteers (mean ± SD: age = 26 ± 6 years, stature = 182 ± 9 cm, body mass = 84 ± 9 kg, with resistance training experience = 7 ± 3 years)	Randomised, double-blind, cross-over study	6mg/kg of anhydrous caffeine 1 hour before testing	Muscular strength and power, muscular endurance, Rate Of Perceived Exertion (RPE), and Pain Perception (PP)	Enhanced lower body strength but no effects on muscular endurance
Lara, et al. (2021) [27]	10 male, 10 female athletes	Double-blind, placebo-controlled, cross-over experimental trial	3mg of caffeine per kg of body mass	Peak and mean cycling power during a 15-s adapted version of the Wingate test	Caffeine enhanced peak and mean cycling power in men and women and the ergogenic effect was of similar magnitude in both sexes.

Potgieter, et al. (2018) [31]	26 triathletes (14 males and 12 females; mean ± SD: age = 37.8 ± 10.6 years, habitual caffeine intake = 413 ± 505 mg/day, percentage body fat = 14.5 ± 7.2%, and training/ week = 12.8 ± 4.5 hr)	Double-blind, randomised, crossover field trial	Microencapsulated caffeine (6mg/ kg body weight) supplemented pre-trial	Effect of caffeine on triathlon event performance	Improved performance; reduction in swim time and time to completion
Ruiz-Moreno, et al. (2022) [28]	Fifteen young and healthy participants (11 men and 4 women)	Double-blind, randomised, cross-over placebo-controlled study. Two experimental days consisting of pedalling for 1 h with a self-selected wattage	3mg/kg caffeine	Effect of oral caffeine intake during self-paced cycling on autoregulated exercise intensity and substrate oxidation.	Increased self-selected intensity and total energy expenditure, but no effect on substrate oxidation
Skinner, et al. (2019) [29]	Twenty-seven (11 women and 16 men) endurance-trained cyclists and triathletes	Randomised, double-blind, placebo-controlled, crossover study	Opaque capsules containing either 3mg/kg body mass of anhydrous caffeine or a placebo	Effect of caffeine on endurance cycling performance in women; impact of sex on ergogenic effect of caffeine	Caffeine enhanced endurance exercise performance in women. The magnitude of the performance enhancement observed in women was similar to that of men, despite significantly greater plasma caffeine concentrations after exercise in women
Smirmaul, et al. (2017) [30]		Seven adult males	Double-blind, randomised, counterbalanced cross-over design	Effects of caffeine on performance, neuromuscular fatigue and perception of effort during high-intensity cycling exercise in moderate hypoxia	Caffeine significantly improved time to exhaustion by 12%. A significant decrease in subjective fatigue was found after caffeine consumption. Perception of effort was lower and heart rate was higher in the caffeine condition when compared to placebo. However, caffeine did not reduce the peripheral and central fatigue induced by high-intensity cycling exercise in moderate hypoxia

men and women in their third and fourth decades, in other words quite a restricted section of the population. Measured outcomes have been different and in the context of different types of exercise and sport making comparisons difficult. Findings are not consistent. The majority of these trials have used doses of caffeine extracts of 3-6mg/kg/bw.

No clear effect was observed on anaerobic capacity and exercise endurance with caffeine 5mg/kg/bw [20]. A dose of 6mg/kg bw improved jump height but not maximal strength [21] whilst the same dose improved jump height in college athletes [22]. A dose of 5mg/kg bw significantly increased muscle power [23] and 8mg/kg bw caffeine improved bench press, dead lift and squat strength compared with placebo [24]. Doses of 3-6mg/kg bw improved maximum strength but with no impact on strength endurance [25,26].

With regards to particular sports, caffeine 3mg/kg/bw improves cycling power [27-29] and time taken to become fatigued [30] Caffeine 6mg/kg bw improves swim time and performance in a triathlon [31].

Several systematic reviews have evaluated the impact of caffeine on exercise and sports performance (Table 5). Moderate doses of caffeine 3-6mg/kg (mostly in the form of extracts) improved muscular strength and endurance in studies involving women [32] and in studies involving both sexes [32-35]. Physical performance in both team sports [36,37] and combat sports [38,39] improves with caffeine intake. Caffeine supplementation also enhances specific sports performance metrics including isometric strength, anaerobic power, reaction time, and anaerobic metabolism [39]. A meta-analysis of 46 studies found that caffeine has a small but significant effect on endurance performance when taken in moderate doses (3-6 mg/kgbw) as well as an overall improvement following caffeine compared to placebo in power output and time to complete an event [40].

Meta-analyses have also evaluated the impact of caffeine extracts on performance in specific sports. In basketball players, pre-exercise ingestion of 3 and 6 mg/kg bw caffeine increased vertical jump height [41,42]. However, two systematic reviews found limited [43] or no

Table 5: Impact of caffeine on physical performance: systematic reviews and meta-analyses.

Reference	Participants	Study design	Intervention	Outcomes	Findings
Arguedas-Soley, et al. (2021) [36]	13 RCTs (231 participants)	Systematic review & meta-analysis	Caffeine extracts: 3-6mg/kg/bw 60 minutes before exercise	Effects of acute caffeine ingestion on physiological parameters, physical and technical-skill performance during team-sport match-play	Higher peak and mean heart rates; higher blood glucose & lactate; improved physical performance (Including greater distances covered; distances covered at speed; impact frequencies
Delleli, et al. (2022) [38]	26 RCTs (323 combat sports athletes)	Systematic review & meta-analysis	Caffeine extracts: 2-10mg/kg/bw	Effect of caffeine supplementation on performance outcomes in combat sports,	Acute benefit on aspects of exercise, including isometric strength, anaerobic power, and reaction time, as well as improved anaerobic metabolism of combat sports athletes
Diaz-Lara, et al. (2022) [39]	25 RCTs	Systematic review and meta-analysis	Caffeine extract	Effect of caffeine on performance variables in combat sports athletes	Caffeine improved vertical jump height & reaction time and various combat sports measures
Gomez-Bruton, et al. (2021) [37]	18 crossover RCTs in 10 countries (240 young adult female sports participants (basketball, volleyball, soccer, rugby, handball, netball, softball, hockey	Systematic review & meta-analysis	Caffeine 1.3-6mg/kg/bw (powders, energy drinks, power bars, coffee) 30-70 minutes before activity	Impact of caffeine on performance in several team games	Caffeine improved intensity during a match; improved performance on specific sports drills (eg throwing a ball); improved upper body strength; improved jump performance; improved handgrip; did not improve agility; did not improve sprint performance
Grgic, et al. (2018) [33]	12 RCTs	Meta-analysis	Caffeine 0.9-2mg/kg/bwTwo studies used 100mg and 400mg doses (1.4 and 5.6mg/kg/bw)	Minimum ergogenic dose of caffeine on resistance exercise outcomes, such as muscular strength, endurance, and velocity	Muscular strength: 0.03-0.31mg/kg/bwMuscular Endurance07-0.35;Mean velocity, 0.12-1.01;
Grgic, et al. (2020) [34]	7 RCTs (5 double blind trials; one single blind; one not blinded); 71 experienced rowers (58 men, 13 women) extract	Meta-analysis	Caffeine extract 1.3-9mg/kg/bw	Effect of caffeine on rowing performance	Caffeine may improve 2000m ergonomic rowing performance with small increases in power
Grgic, et al. (2022) [35]	12 RCTs	Meta-analysis	Caffeine extract 0.9-2mg/kg	Impact of caffeine on muscular strength, endurance and velocity	Ergonomic effect of caffeine on muscular strength, endurance and velocity with doses of 1-2mg/kg
Grgic, et al. (2021) [32]	8 crossover RCTs (98 female athletes)	Meta-analysis	2-6mg/kg/bw	Impact of caffeine on muscular strength and muscular endurance	Significant impact of caffeine on muscular strength and muscular endurance
Grgic , et al. (2022) [46]	10 double or triple blind studies (151 participants, 40 female, 111 male)	Meta-analysis	Extracts: 2-12 mg/kg/bw	Effect of caffeine on throwing performqnce	Small, significant ergogenic effect on throwing performance. Caffeine < 3mg/kg/bw or >3mg/kg/bw likely to be ergogenic fo1212r throwing distance and throwing velocity
			Caffeine gum 100mg caffeine		
			Caffeine gel: 75mg		
Lazic, et al. (2022) [41]	8 RCTs; 120 basketball players	Meta-analysis	3mg/kg/bw (7 studies) 6mg/kg (1 study) 60 minutes before the game	Impact of caffeine on basketball players	Caffeine significantly increases vertical jump performance, sprint performance without the ball, planned agility, number of three throws, rebounds, assists, and body impacts during simulated matches. Equivocal results were found for endurance, accuracy, and dribbling speed

Mielgo-Ayuso, et a.l (2019) [43]	10 RCTs (221 athletes (113 males;108 females)	Systematic review	Caffeine : 3-6mg/kg/bw 30-60 minutes before testing; from drinks, powders, coffee	Effect of caffeine on sports performance	A similar ergogenic benefit for aerobic performance and the fatigue index in men and women athletes. Increase in power, total weight lifted and sprint performance were greater in men than women athletes
Southward, et al. (2018) [40]	46 RCTs	Meta-analysis	Caffeine 3-6mg/kg/bw	Effect of caffeine on endurance time-trial performance	Improved power and time-trial completion time
Tan, et al. (2021) [42]	10 RCTs	Meta-analysis	Caffeine 3-6mg/kg	Basketball performance outcomes	Improved vertical jump, agility, and linear and repeated sprints. No impact on basketball skills
Wang, et al. (2022) [47]	21 RCTs; 254 participants, including 220 men, 19 women and 15 participants with no information about gender.	Systematic review and meta-analysis	Caffeine 3-9mgkg/bw	Ergonomic effects in runners	Pre-exercise caffeine supplementationshowed a mediumsize ergogenic effect to increase the time to exhaustion in running trials and a small-size effect to improve performance in running time trials

[44] impact of caffeine on soccer performance. A meta-analysis of 16 studies found a small positive effect on handgrip strength, particularly in men, from caffeine supplementation in small doses (1-3 mg/kg bw), moderate doses (5-7mg/kg/bw), in liquid form and in capsule form [45]. Small doses < 3mg/kg/bw were effective on throwing performance. Including throwing velocity in a meta-analysis of 10 studies [46]. A meta-analysis of 21 RCTs employing caffeine doses of 3-9mg/kg bw including 220 men and 19 women found that caffeine reduced time to exhaustion in running and reduced running time [47].

Risks of Caffeine

Caffeine is a psychostimulant which, at inappropriate doses for individuals, have been linked with negative health impacts. There is evidence that adjustments to the dose, frequency, vehicle (supplement *versus* beverage) and timing of caffeine ingestion are suitable mitigations. Relevant studies are discussed in this section.

Brain, Sleep and Mental Health

Large, but not low or moderate, doses of caffeine have been associated with stress and anxiety, particularly in women [48]. High intakes of caffeine (400-750mg) have been linked with increased anxiety and panic but mainly in people with underlying panic disorder [49].

Caffeine intake is associated with poor sleep, especially if consumed close to bedtime. Older people are more sensitive than younger adults to these effects of caffeine, although there are individual differences and genetics has an impact. A recent systematic review found that high doses of caffeine increased sleep latency, reduced total sleep time and sleep efficiency, and worsened perceived sleep quality. Slow-wave sleep and Electroencephalographic (EEG) slow-wave activity were typically reduced, whereas stage-1, wakefulness, and arousals were increased [50]. In good sleepers who habitually consume caffeine, daily caffeine intake in the morning and afternoon did not impact nighttime sleep structure or subjective sleep quality [51].

High intakes and regular exposure to caffeine may cause headaches, with withdrawal headaches and dependency also occurring. However, caffeine also appears to have an ambiguous role in headaches, particularly migraine, acting both as a trigger and a treatment [52].

Hydration and Voiding

Caffeine has been vilified for increasing urinary frequency, urgency and kidney stones. However, research is conflicting. One study in 491 older men and women (median age=63 years) found that, whilst people with urinary urgency tend to avoid caffeine, amongst those who habitually consume caffeine, the amounts consumed were similar in groups with and without urinary urgency, suggesting that there may be a subset of people who are caffeine sensitive [53]. A study of 4309 non-pregnant US women over the age of 20 years who completed caffeine and urinary incontinence diaries found the prevalence of urinary incontinence was 41% in this population but only caffeine intakes>204mg daily were linked with incontinence [54]. A meta-analysis of seven studies (one case-control, one cohort, two cross-sectional) found no evidence for an association of caffeine intake and the risk of urinary incontinence in adult men or adult women [55]. A meta-analysis of 13 studies found no evidence that naturally caffeinated beverages, coffee and tea, increase the risk of kidney stones. Moderate consumption of coffee had no impact on the risk of kidney stones in this analysis and tea was generally protective against kidney stones [56].

Caffeine intake has been linked to dehydration although evidence supporting this has come from research using high dose caffeine pills. This does not reflect usual consumption of caffeine from beverages both in terms of caffeine dosage and concurrent consumption of water. A meta-analysis of 16 studies, where the median caffeine dose was 300mg daily, found that caffeine increased urine production by 16% with women more susceptible to diuresis than men. In this review, exercise strongly moderated the diuretic effect [57]. A randomised controlled cross-over trial evaluating the hydration status of 21 men after the consumption of four or six cups of tea, providing 168mg or 252mg caffeine found no significant differences in markers of hydration between treatment groups and boiled water control [58].

Cardiovascular Health

Caffeinated beverages are often under scrutiny for adverse cardiovascular effects. Studies in humans yield inconsistent results dependent on the study population and the vehicle (i.e. drink or pill) or dose of caffeine but with moderate amounts ≤ 400mg daily demonstrating more benefit than harm in markers, such as blood

pressure and blood vessel elasticity. The dose at which caffeine may cause adverse cardiovascular effects is not readily identifiable as few high dose studies (e.g. >600mg daily) have been conducted [59]. In the UK Biobank Study, >2 servings of tea each day were associated with reduced cardiovascular mortality [60]. A systematic review of 19 meta-analyses and 13 RCTs (which included 1422 participants) found that tea drinking in general improves vascular health with 4-5 cups of black or green tea related to reduced risk of hypertension [61].

Vulnerable Groups

Several national bodies recommend that pregnant women limit caffeine intake because of risk to the foetus. However, data on foetal safety are inconsistent. A US longitudinal pregnancy cohort study with a final sample size of 2583 women from 12 US clinical sites found that second trimester caffeinated beverage intake within current recommendations ≤ 200mg daily during pregnancy) was associated with lower gestational diabetes mellitus risk and lower glucose concentrations, lower C-reactive protein and C-peptide concentrations and beneficial lipid profiles [62]. Total plasma caffeine and paraxanthine at 10 to 13 weeks of pregnancy was inversely associated with glucose. No associations were observed with preeclampsia or gestational hypertension. A prospective cohort study of 15,590 pregnancies from 11,072 women with no history of spontaneous abortion found that pre-pregnancy caffeine intake >400mg daily was associated with increased risk of spontaneous abortion. However, no similar associations were found with pre-pregnancy intake of caffeinated tea and soda [63]. High consumption of caffeine has been associated with lower birth weight in some [64,65] but not all [66] meta-analyses. A recent US longitudinal cohort study involving 2055 pregnant women found that infant birth weight and infant lean body mass were actually lower in mothers complying with the recommendation to consume <200mg caffeine daily [67].

Studies in children are limited in number but suggest dose-response relationships between daily caffeine consumption and adverse effects. In a recent review [68] the author suggests that typical, moderate caffeine consumption in children and adolescents is relatively safe, but that higher doses (>400 mg) can cause physiological, psychological, and behavioural harm, in particular in children with underlying psychiatric or cardiac conditions. In one acute study, children aged 8-9 years and adolescents aged 15-17 years consumed a beverage containing 0, 1 or 2mg caffeine/kg bw [69]. Risk taking behaviour increased with higher caffeine consumption in a dose dependent manner. A prospective cohort study in 309 Australian children aged 8-12 years evaluated the impact of caffeine on sleep and behaviour [70]. Total caffeine consumption was significantly associated with sleep routine, morning tiredness, restless sleep and internalising behavioural problems. In a large cohort of secondary school children in the South-West of England, weekly caffeine intake was associated with stress, anxiety and depression [71]. This suggests that managing caffeine dosage in relation to body weight is critical to prevent adverse effects in children. Many of these studies used pills and there is limited data on how children would respond to caffeinated beverages such as tea.

Expert Body Recommendations

Several expert and national bodies have published recommendations for caffeine intake (see Table 6). Adults can safely consume up to 300mg-400mg of caffeine a day while recommendations for under 18s are 2.5 mg/kg bw for children and ≤ 100 mg/day for adolescents. In the UK, there are no official recommendations for daily caffeine limits in healthy children and adults. However, pregnant women are advised to consume ≤ 200mg caffeine daily [72].

Table 6: Intakes of caffeine by country or region and population group (from Verster & Koening 2018).

Country	Population group	Caffeine intake (mg/day)
UK	4-6 years	Mean =46mg
	10-12 years	Mean =85mg
	Adults	122-143 mg
US		
Non-consumers included	Adults ≥ 19 years	Mean = 186 ± 4mg
	Men	Mean = 211 ± 5 mg
	Women	Mean = 161 ± 3 mg
Consumers	2-11 years	Mean = 25mg
	12-17 years	Mean = 75mg
	50-59 years	Mean = 250mg
Consumers	Adults ≥19 years	Mean = 211 ± 3 mg
	Men	Mean = 240 ± 4 mg
	Women	Mean = 183 ±3 mg
	90th/99th per centiles	436mg/1066mg
Europe (22 European countries) (EFSA 2015) [73]	Toddlers	0.3-30.3mg (0.0-2.1mg/kg/bw
	Children	3.5-47.1mg (0.2-2.0mg/kg/bw)
	Adolescents	17.6-69.5mg/kg/bw (0.4-1.4mg/kg/bw)
	Adults	365-391.4mg (0.4-4.3mg/kg/bw)
	Older people	22.6-362.1mg (0.3-4.8mg/kg/bw)
	Very elderly people	21.8-416.8mg (0.3-6mg/kg)
Australia (Australian Bureau of Statistics (2012)	Adults	101-183mg
New Zealand (National Adults Nutrition Survey)	People >15 years	216mg (2.8mg/kg)
	Boys 15-18 years	75mg (1.1mg/kg/bw)
	Girls 15-18 years	77mg (1.2mg/kg/bw)
	Men 19-30 years	194mg (2.4mg/kg/bw)
	Women 19-30 years	144mg (2.4mg/kg/bw)
	Men 31-50 years	253mg (3.3mg/kg/bw)
	Women 31-50 years	252mg (3.5mg/kg/bw)
	Men 51-70 years	264mg (3.4mg/kg/bw)
	Women 51-70 years	212mg (3mg/kg/bw)
	Men>70years	216mg (2.7mg/kg/bw)
	Women>70 years	179mg (2.7mg/kg/bw)
South Korea From Verster & Koening 2018	Whole population	66.75mg
	Males	77.24mg
	Females	58.23mg
	Adults ≥ 19 years	81.91mg
	15-18 years	30.04mg (0.52mg/kg/bw)
	0-3 years	1.38 (0.11mg/kg/bw)
	12-14years	10.05mg (0.19mg/kg/bw)
	30-49 years	101.83mg (1.55mg/kg/bw)

The European Food Safety Authority [73] reports that single doses of caffeine ≤ 200 mg (around 3 mg/kg bw for a 70kg adult) do not give rise to safety concerns. For habitual caffeine consumption, acceptable upper levels for safety would be ≤400 mg daily for non-pregnant adults and ≤ 200 mg daily for pregnant women. In addition, single doses of caffeine and habitual caffeine intakes up to 200mg daily consumed by lactating women do not give rise to safety concerns for their breastfed infants. According to EFSA, the available evidence is insufficient to derive a safe caffeine intake for children and adolescents.

Several European countries comment on caffeine and caffeinated beverages in their dietary guidelines (reviewed in [74]. Some are non-specific stating that caffeinated drinks should be limited (e.g., Albania), moderated (e.g., Italy, Poland) or, in children, avoided (e.g., Albania). The main issue stated by other countries is to avoid adding sugar to hot caffeinated beverages (e.g., Albania, Bulgaria, Malta, Turkey). Austrian guidelines condone moderate consumption of black tea (3-4 cups daily), coffee and other caffeinated drinks. Public authorities in the UK, Belgium, France, Ireland and Switzerland recognise the contribution of tea and coffee to daily fluid recommendations. The UK Eat well Guide states that sugar-free drinks such as tea and coffee can contribute to the recommendation to drink 6-8 glasses of fluid each day [75]. Belgium's guidance states that tea, coffee and water are components of a good breakfast in teenagers aged 13-18 years. Older adults (aged 60 years and over) are encouraged to include water, but also tea or weak coffee, for hydration and to consume sources of antioxidants at each meal. Belgium recommends the avoidance of large amounts of caffeine in pregnancy whilst Ireland recommends a limit of 200mg caffeine daily in pregnancy. For the general adult population, Danish guidelines recommend no more than 400mg caffeine each day whilst Portugal recommends no more than 300mg daily. Both Latvia and Poland promote the consumption of herbal teas rather than black tea or coffee for hydration. Of note, the Netherlands actively recommends drinking three cups of tea (green or black) each day. Romania identifies tea as a source of antioxidants.

The US Food and Drug Administration [76] consider that 400 mg caffeine (about 4 cups brewed coffee or 8 cups of tea) is a safe amount for healthy adults to consume daily. However, pregnant women should limit their caffeine intake to ≤ 200 mg a day (around 2 cups brewed coffee or 4 cups of tea), according to the American College of Obstetricians and Gynecologists [77]. The American Academy of Pediatrics suggests that children under age 12 should not consume any food or beverages containing caffeine. For adolescents 12 and older, caffeine intake should be limited to no more than 100 mg daily.

The focus in Latin American countries (reviewed in [74]) is on reducing sugar in beverages rather than restricting caffeine. Mexico advises limiting the intake of unsweetened coffee, 'fruit water' and fruit juice to four cups daily. African and Asian countries also tend to focus on limiting sugar in drinks. Fiji and Lebanon authorities state that tea and coffee need to be consumed with plenty of water due to a diuretic effect. India advises caution with caffeine intakes >200mg and, like Sri Lanka, Qatar and Lebanon, suggests that tea may reduce iron absorption, which is the subject of conflicting studies.

In Canada, the guidelines from Health Canada [78] are that adults (18 years and over) should consume ≤ 400mg caffeine daily. Women who are pregnant, planning a pregnancy or breast feeding should consume ≤ 300mg. For children and adolescents up to 18 years, caffeine intakes should be ≤ 2.5mg/kg bw. For a typical sized child, this equates to no more than 45mg a day for 4-6 year olds, 62mg for 7-9 year olds and 85mg for 10-12 year olds. A meta-analysis of 380 studies determined whether these recommended limits for caffeine consumption remain appropriate for six health outcomes (acute toxicity, cardiovascular toxicity, bone and muscle, effects on calcium, behavior and development, and reproduction in healthy adults, pregnant women, adolescents and children). The updated evidence confirmed that the age-adjusted levels of caffeine intake in Health Canada's guidelines were not associated with any adverse health effects [79].

Food Standards Australia and New Zealand state that healthy adults can generally consume around 400mg of caffeine a day - that is two (50mL) espresso coffees, five (250mL) energy drinks or eight cups of tea (see table 1). Children should restrict daily caffeine intake to ≤ 3mg/kg bw [80].

Caffeine Consumption

A review of national studies [81] found that mean total daily caffeine intakes (averaged across several European countries, the United States, Canada, Australia and New Zealand) in children, adolescents, and adults were below the national recommendations of Health Canada [77] and EFSA [72]. As a reminder, these are ≤ 2.5 mg/kg bw/day for children and adolescents, and ≤ 400 mg/day for adults (Canada) and ≤ 3 mg/kg bw/day for children/adolescents and ≤ 400 mg/day for adults (EFSA). Total daily caffeine intake has remained stable in the last 10-15 years, with coffee, tea and soft drinks representing the most important sources. Energy drinks contribute little to total caffeine intake [79] except in children where, taking exposure per kg body weight into account, energy drinks can represent half of all caffeine consumed [82].

National Studies

Tea is the main source of caffeine in the UK (providing 57% of the national caffeine) [77] while, in Ireland, 59% of caffeine is derived from tea. Data from the National Diet and Nutrition Survey from 2008-2010 in a representative sample of 2,126 UK inhabitants aged 1.5 years and over found that total caffeine intake in adults ranged from 122mg to 143mg daily [83]. Mean caffeine intake of younger participants varied from 46mg daily in 4-6 year olds to 85mg daily 10-12 year olds. Overall, more than 95% of UK caffeine consumers have intakes below the safe levels recommended by Health Canada. Mean caffeine intake identified in a 2015 US study [84] was 186mg daily when non-consumers were included and 211mg daily when consumers alone were analysed. Caffeine intake data from other countries is summarised in table 7.

Potential Toxicity

Caffeine can be toxic in high doses and, in general, will begin to affect the body when blood levels exceed 15mg/litre. Toxicity is most likely to result from taking a caffeine extract or pure caffeine powder in dietary supplement form. This bears no relevance to real life consumption of naturally caffeinated beverages.

The response to high doses of caffeine is individualised and depends on general health, age, weight and height. National dietary guidelines generally recommend ≤ 400mg caffeine daily as safe for an adult which is equivalent to eight cups of tea or four cups of coffee depending on the strength. As foetuses and infants are less able to break down caffeine quickly [85], national guidelines suggest lower intakes of caffeine during pregnancy and breast feeding.

Discussion

Moderate amounts of caffeine (3-6mg/kg/bw) have positive effects

Table 7: Key expert body caffeine recommendations.

Body	Summary of recommendations
UK	No clear recommendations for daily caffeine limits, either for children or adults
	The NHS suggests that pregnant women consume no more than 200mg caffeine daily
European Food Safety Authority (EFSA)	Single doses of caffeine up to 200 mg (about 3 mg/kg bw for a 70-kg adult) do not give rise to safety concerns.
	Habitual caffeine consumption up to 400 mg per day does not give rise to safety concerns for non-pregnant adults.
	Habitual caffeine consumption up to 200 mg per day by pregnant or lactating women does not give rise to safety concerns for the foetus
	For children and adolescents, the information available is insufficient to derive a safe caffeine intake
Food Standards Australia and New Zealand	Healthy adults can generally consume around 400mg of caffeine a day
	Children should consume less than 3mg for each kilo of body weight a day
United States Food and Drug Administration (FDA)	400 milligrams is considered a safe amount of caffeine for healthy adults to consume daily
	This is the amount in two or three 12-ounce cans of cola soda
American College of Obstetricians and Gynaecologists	Pregnant women should limit their caffeine intake to 200 mg a day
American Academy of Paediatrics	Children under 12 should not consume any food or beverages with caffeine
	Adolescents 12 and older, caffeine intake should be limited to no more than 100 mg daily
Health Canada	Adults (18 years and over): no more than 400mg
	Women planning to be pregnant: no more than 300mg
	Women who are pregnant or breastfeeding: no more than 300mg
	For children and adolescents up to 18 years, no more than 2.5mg/kg 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: 45mg
	Aged 7-9 years: 62.5mg
	Aged 10-12 years: 85mg

on cognition, including mood and concentration, and behaviour. The ergogenic properties of caffeine in terms of improved physical performance, when consumed in low to moderate doses (3-6mg/kg/bw), are well established with a reduced perception of effort during exercise and increased speed and accuracy of reactions. A recent meta-analysis of 12 studies suggested that even lower caffeine doses (1-2mg/kgbw) produce an ergogenic effect in terms of resistance performance [34]. Higher doses (>9mg/kg/bw) have not been consistently associated with further improvements in performance.

Caffeinated beverages offer many health benefits based not only on their moderate caffeine content (≤ 50mg per cup for black tea) but their range of polyphenolic compounds. These include catechins which are associated with benefits to cardiovascular health [86], metabolic health [87], brain health [88] and bone health [89]. Regular daylong tea consumption provides the same boost to alertness as coffee, but without the sleep disruption [90]. Several other types of tea, such as green, oolong and white tea, contain lower concentrations of caffeine than black tea (see Table 1) but with similar health benefits. Herbal and fruit teas, including chamomile, ginger, hibiscus and rooibos, are devoid of caffeine.

Tea also contains L-theanine, which acts alongside caffeine to improve attention and mood whilst reducing the psychostimulant impact of caffeine. A 2017 review of 49 human intervention studies evaluating research on the psychoactive effects of L-theanine, caffeine and epigallocatechin (EGCG) (a polyphenol in green tea) found that L-theanine and caffeine had clear beneficial effects on sustained attention, memory, and suppression of distraction. Moreover, L-theanine was found to increase perceptions of relaxation by reducing caffeine induced arousal [89]. Caffeine (at doses >40mg) was found to improve performance in demanding long-duration cognitive tasks and self-reported alertness, arousal, and vigour. L-theanine alone improved self-reported relaxation, tension, and calmness at amounts ≥ 200 mg. But L-theanine and caffeine combined were found to particularly improve performance in attention-switching tasks and alertness, but to a lesser extent than caffeine alone [91].

Tea also provides fluoride, which benefits oral health by reducing the risk of dental caries [92], and polyphenols which reduce inflammation and have antibacterial effects. Tea is the most commonly consumed beverage in the world after water and is a safe and useful source of hydration. Energy drinks on the other hand provide higher caffeine contents, particularly when sold as 'shots', and are associated with health risks such as restlessness, anxiety, poor sleep, shakiness, headache, increased breathing rate and increased heart rate or irregular heartbeat [93].

In summary, caffeinated drinks, in particular tea which is at the lower end of the naturally occurring caffeine range for beverages, provide more health benefits than risk. Moreover, data show that average caffeine intakes in most countries, including the UK, are below the upper levels recommended by Health Canada and EFSA, although some individuals have higher intakes. In the UK 95% of the population have a caffeine intake below EFSA's recommended upper levels, with older people having the highest intakes.

One of the key limitations in the evidence based literature on caffeine is the paucity of studies looking at caffeine consumption in different age ranges, particularly children, and in males and females across different age ranges. Also of note is that the majority of studies emerge from the United States where caffeine is most commonly consumed in the form of coffee rather than tea. In addition many studies provide caffeine extracts and supplements – often at very high doses-rather than beverages to evaluate the effects of caffeine.

Conclusion

The available evidence and expert panel recommendations suggest that caffeine intakes of ≤6mg/kg/body weight daily are both safe and beneficial for health with several national guidelines recommending ≤400mg daily for adults. This equates to 8 cups of tea daily for an adult although the majority of health benefits for tea have been observed at intakes of around four servings daily, equating to a caffeine intake of around 200mg . For children aged 4 years and above, caffeine intakes of

2.5mg/kg/bw may be considered safe and appropriate. This equates to a daily consumption of 1-2 cups of tea for young children and 2-3 cups of tea for older children. In the UK, dietary surveys show that average caffeine intakes are within EFSA recommended upper levels with 95% of people having intakes within this limit. The benefits of consuming caffeine from tea rather than other beverages, such as energy drinks, sports drinks and high caffeine dietary supplements, are clear in that the polyphenol, L-theanine and fluoride content of tea is associated with a range of health benefits while tea is also recognised as a healthy source of hydration.. The UK Eat well Guide states that sugar-free drinks such as tea can contribute to the recommended 6-8 glasses of fluid each day [79]. Several teas contain lower concentrations of caffeine than black tea such as decaffeinated black tea, green tea, white and oolong teas. Herbal and fruit teas, including chamomile, ginger, hibiscus and also rooibos, are devoid of caffeine whilst providing health benefits related to their antioxidant content. More research is needed on appropriate doses of caffeine in children, particularly upper tolerable levels, but milky tea without sugar is an appropriate healthy drink for everyone over 4 years of age.

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